DUTCH PERSPECTIVE ON COASTAL LOUISIANA

FLOOD RISK REDUCTION AND LANDSCAPE STABILIZATION

First Interim Report

by

Jos Dijkman (Editor)
(April 2007)

United States Army

EUROPEAN RESEARCH OFFICE OF THE U.S. ARMY

London, England

CONTRACT NUMBER N62558-07-C-006

Netherlands Water Partnership

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
23-04-2007	Interim Report	March 2007-April 2007

4. TITLE AND SUBTITLE

Dutch Perspective on Coastal Louisiana Flood Risk Reduction and Landscape Stabilization

5a. CONTRACT NUMBER

N62558-07-C-0006

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Jos Dijkman (editor)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Netherlands Water Partnership
Westvest 7
2601 AD Delft, The Netherlands

8. PERFORMING ORGANIZATION REPORT NUMBER

WL-Z4307

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

USACE ERDC European Research Office
Edison House
223 Marylebone Road
London NW15TH
United Kingdom

10. SPONSOR/MONITOR'S ACRONYM(S)

USACE ERDC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT

First Interim Report, published halfway the project duration. With the objective to research at reconnaissance level options for the reduction of flood risk and landscape stabilization in planning areas 1 and 2 of LACPR in coastal Louisiana, the report formulates a planning framework, identifies possible measures and alternative strategies, and a work plan for the remainder of the project. Appendices provide background information.

15. SUBJECT TERMS

Coastal Louisiana, flood risks, landscape stabilization.

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	187	19b. TELEPHONE NUMBER *(Include area code)*

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Preface

After the disaster that hurricane Katrina caused along the Gulf coast and in particular in New Orleans (August-September, 2006), many in the United States looked at how the Netherlands protects itself against extreme flood events. Flood protection levels in the Netherlands, by international comparison, are very high but nevertheless affordable. Would the strategy followed by the Dutch not be the example that should be used when considering the long-term flood risk management in Louisiana? And given the rapid loss of wetlands in the Mississippi Delta, could Louisiana benefit from the recent change in policy in the Netherlands, in which preference is shifted from only relying on traditional approaches involving levees and flood barriers towards ‘building with nature’ in combination with traditional approaches?

The current planning activities in the framework of the Louisiana Coastal Protection and Restoration project (LACPR) aim to develop alternative strategies for long-term flood risk management options as well as for restoration of the rapidly deteriorating Mississippi Delta. In common language: LACPR focuses on both flood protection for Category 5 hurricanes and coastal restoration.

Since Katrina, the existing co-operation between the US Army Corps of Engineers (USACE) and the Netherlands Rijkswaterstaat (under the Netherlands Ministry of Transport, Public Works and Water Management) has intensified and shifted its primary focus on shared flood management issues. In the framework of this co-operation, the idea developed to draft a Dutch perspective on the topics covered by the LACPR project, i.e. flood risk reduction and landscape stabilization. As a result, a consortium under the Netherlands Water Partnership (an umbrella organization of Dutch governmental organizations, contractors, consultancy firms and research institutes) was commissioned by USACE to carry out a research and planning project entitled ‘Dutch Perspective on Coastal Louisiana Flood Risk Reduction and Landscape Stabilization’.

Many of the specialists involved in this Dutch Perspective project visited New Orleans and the Mississippi Delta after Katrina and were involved in meetings and workshops with USACE and other organizations in Louisiana. The various Internet sites provided an overwhelming amount of information and the project team reviewed in great detail reports drafted in the framework of LACPR and Louisiana’s Comprehensive Master Plan for a Sustainable Coast (by the Coastal Protection and Restoration Authority of Lousiana, CPRA). The progress in analyzing Katrina and her effects is impressive and many of the Dutch team started wondering what a group of specialists from the Netherlands actually could contribute to this process of evaluation and planning. At the same time, the team is proud to be involved in finding flood risk management solutions beneficial to the people of Louisiana.

For the people in the Netherlands, and in particular for those involved with the flood protection system, Katrina served as an eye-opener. Catastrophic flooding could also happen in the Netherlands, especially if attention is weakened or the forces of nature are under-estimated. What would the Dutch do, what would be their response to a major disastrous flooding in the Netherlands? The US eyes looking to the Netherlands as an example of doing things right brought reflection on the Dutch response to the 1953 flooding disaster.

What were the main decisions taken and how does it translate or compare to what might be the right way for Louisiana? The Dutch response to the 1953 disaster built on eight centuries of dedication to protect the country against rising water. The recorded history of the Louisiana people struggling against rising Mississippi water and hurricanes may not be that long, but is at least as dynamic. There are many books that provide excellent documentation on various floods and hurricanes in the US for a common audience. These are a compulsory read for the experts involved in the Dutch team to at least try to understand some of this.

The assignment by USACE to the Dutch Team is not intended to bring up a comprehensive master plan for the Mississippi Delta as an alternative for or in competition with that of LACPR or CPRA. It merely tries to contribute to it, in an attempt to translate the Dutch experience to the Mississippi Delta, and compare technologies that might or might not differ to what American engineers and scientists know and can do. The project team fully appreciates the differences in background and political context and realizes that there is not a single truth or wisdom. The Dutch team will, however, make certain choices as to what planning principles and measures will be selected for further investigation and, in the end, will be included in the final report as recommendations.

For this research and planning project, the Dutch team will not have direct consultation with the people and communities involved, some of which might directly be affected with the consequences of certain principles or measures recommend in this report. Also, vested local interests in land ownership, and rules and regulations regarding for example the mitigation of ecological impacts, are deliberately not taken into account in this planning effort. This in order to come up with a truly outsiders' perspective on the issues at stake. A perspective that is as much as practically possible not colored by local opinions about the preferred course of action.

It goes without saying that deciding about which course of action to pursue is up to the people of Louisiana and of course the US Congress. The project team hopes that the Dutch perspective contributes to making informed decisions about what is the best course of action for the Louisiana coastal area and New Orleans in particular.

Contents

1 Introduction .... 1—1

2 Project area overview .... 2—1

3 Approach .... 3—1

4 Possible measures .... 4—1

5 Alternative strategies .... 5—1

6 Management and maintenance .... 6—1

7 Conclusions and recommendations .... 7—1

8 Work plan for the remainder of the project .... 8—1

Appendices with background information:

A Planning Framework and Criteria A–1

B Description of the physical delta system: geology B–1

C Description of the physical delta system: wetlands C–1

D Hydraulics and morphology D–1

E Values to be protected and optimal flood protection levels E–1

F Soft soil engineering and structures F–1

G Potential measures and strategies G–1

H Strategy development and impact assessment H–1

I Management and Maintenance I–1

J Lessons learned in Dutch water management J–1

K Project team K–1

1 Introduction

Context of the project

The project entitled Dutch Perspective to Coastal Louisiana Flood Risk Reduction and Landscape Stabilization is being realized in the framework of the Louisiana Coastal Protection and Restoration project (LACPR).

Ongoing co-operation between the US Army Corps of Engineers (USACE) and the Netherlands Rijkswaterstaat (under the Netherlands Ministry of Transport, Public Works and Water Management) led to the idea to develop a Dutch perspective on the topics covered by the LACPR project, i.e. flood risk reduction and landscape stabilization. As a result, a consortium under the Netherlands Water Partnership (NWP, an umbrella organization of Dutch governmental organizations, contractors, consultancy firms and research institutes) was commissioned by USACE to carry out this project.

Project objective

The objective of the project is to draft a plan for the long-term flood risk reduction and landscape stabilization of part of coastal Louisiana, possibly enhancing the local and regional economy.

The level of detail in the project is that of a reconnaissance study. Hence, it does not reach the level of a feasibility study, let alone detailed designs of possible measures or strategies.

To fit in the time schedule of the LACPR Project, the Dutch Perspective will be completed by the end of June 2007, three months after commissioning.

This report attempts to be clear on the options and the kind of measures to be taken into consideration, and provides suggestions for the order by which measures should be taken over time to implement the strategy. The report intends to contribute to the ongoing planning effort in the framework of LACPR.

This report is only a small step in a long process of re-evaluation of flood risk management and landscape stabilization in Louisiana. A relatively small endeavor like this is by no means sufficient to obtain a detailed picture on the diverse development issues, to resolve the divergent views around complicated issues existing in the area, and it is certainly not sufficient to draft an integrated plan, ready for implementation. It can only contribute to the process of decision-making, and that is what the Dutch team hopes to achieve with this “outsiders’ perspective”.

Project area

The Dutch Perspective project will be limited to the LACPR Planning Areas 1 and 2 (see Figure 1), namely the Pontchartrain basin and the Barataria basin. This is in contrast to the project area for the LACPR Project, which focuses on the entire coastal area of the State of Louisiana.

Figure 1 Schematic map indicating Planning Areas 1 and 2 (source: LACPR)

Approach

This project has been conducted in the Netherlands using specific information provided by USACE, as well as publicly available information from USACE and other websites. Direct consultation with the people and communities involved is deliberately not sought by the project team. This is to ensure that the team comes up with a truly outsiders' perspective.

Activities to date

The project officially started on March 30, 2007, with the signing of a contract by USACE and NWP. Before that date, however, project activities already started by wish and order of the Netherlands Rijkswaterstaat to enable team mobilization, data gathering and scope tuning.

Activities to date included:

- A familiarization of the project team with the problem at hand, which included literature reviews, various field visits and discussions with numerous US experts on a variety of topics (in particular during the week of 12 to 16 March, 2007);
- Study of the various components of the delta system, including geology, hydraulics, morphology, ecology, flood risks, soil mechanics and options for a variety of structural flood protection measures;
- Developing a long list of possible interventions in the delta system; and
- Creating an overview of alternative strategies for long-term flood risk reduction and landscape stabilization.

Acknowledgements

The project team thanks the many US experts contacted during the project activities for their useful suggestions and help during the project. In particular, the help, guidance and constructive comments given by Dr. Edmond Russo, Dr. Al Naomi and Dr. Carl Anderson (all USACE) during the project are gratefully acknowledged. The authors of this report remain solely responsible for the way the input was condensed and presented in this report.

The NWP Consortium for this project

The Netherlands Water Partnership is an independent foundation set up by the Dutch private and public sectors in the Netherlands to act as a national coordination and information centre for water-related issues abroad. The NWP is the channel through which government bodies, NGO's, research institutes and private organizations in the water sector share information on their activities and services. The NWP has currently 135 members: 71 private sector companies, 24 public authorities, 19 knowledge institutes, 14 NGO's and 7 water supply companies.

For the Dutch Perspective project, NWP has set up a team of specialists, which is composed of staff members of the following member organizations of NWP: WL | Delft Hydraulics, Arcadis, DHV, GeoDelft, TNO, Royal Haskoning, Fugro, Alkyon, HKV Consultants and Infram, with important contributions from Rijkswaterstaat-experts. Appendix K lists the members of the project team.

Overview of the contents of this report

The objective of this Interim Report is to consolidate results achieved to date, roughly halfway the project, which formally started on 30 March, 2007.

This report consists of a concise main part, with many appendices. The appendices provide background information on the various main focus areas of the work that is being carried out. A work plan for the remainder of the project is included in this report.

The report has all the markings of a work in progress. Given the very short amount of time available for a project (three months in total), no attempt has been made to write this Interim Report as a 'stand-alone' report. As a consequence, the text of the report – in particular in the appendices – is not well balanced as yet, and the work is clearly not finished yet.

2 Project area overview

2.1 Overview of the existing situation

To be addressed, awaiting a description of the existing situation to be made available to the Dutch Perspective team by LACPR.

- *Metropolitan area New Orleans*
- *Open delta system*
- *Functions to society: housing, industry, navigation, fisheries, recreation, etc.*
- *Levees*
- *Subsidence / land loss (including causes)*
- *Existing flood risks.*

System description: here a summary of the appendix on geology / ecology / hydraulics & morphology

*In coastal Louisiana, the following two **main** issues are at stake: flood risk reduction and the degradation of the environmental values of the delta. Developments in flood management are of great importance for the protection of the population and economic activities. Economic development can be the result of improvements made in flood management, but can also be stimulated by increased tourism and fisheries resulting from improved environmental conditions. In this line of reasoning, economic development is not an issue in itself. It goes without saying that there are other important issues related to the various functions of the river (recreation, drinking water supply, navigation, etc.). The Dutch team feels these issues are currently not the main issues to focus upon in this report.*

2.2 Future situation without measures

To be addressed, pending a description of the future situation without measures to be made available to the Dutch Perspective team by LACPR.

assumption on sea level rise (follow IPCC)

Assumption: the distribution of Mississippi River water at the Old River Structure remains unchanged.

2.3 Lessons learned in Louisiana and in the Netherlands

Looking back into history, it can be concluded that the present state of both the Mississippi Delta and Netherlands Delta are shaped by human intervention. There are many differences as to geology, scale and type of interventions and land-use, but is it obvious that both deltas are beyond a ‘free’ natural state. Both deltas adapted and still are adapting to man-made conditions. In the Netherlands, these interventions span ages dating back to roughly the

tenth century. Significant interventions in the Mississippi Delta date back some two centuries. In both deltas flooding through rivers or the sea triggered swift and large-scale interventions, and were the main force for finding quick and proven solutions. Immediate action was and is required to be prepared for the next flooding or storm season.

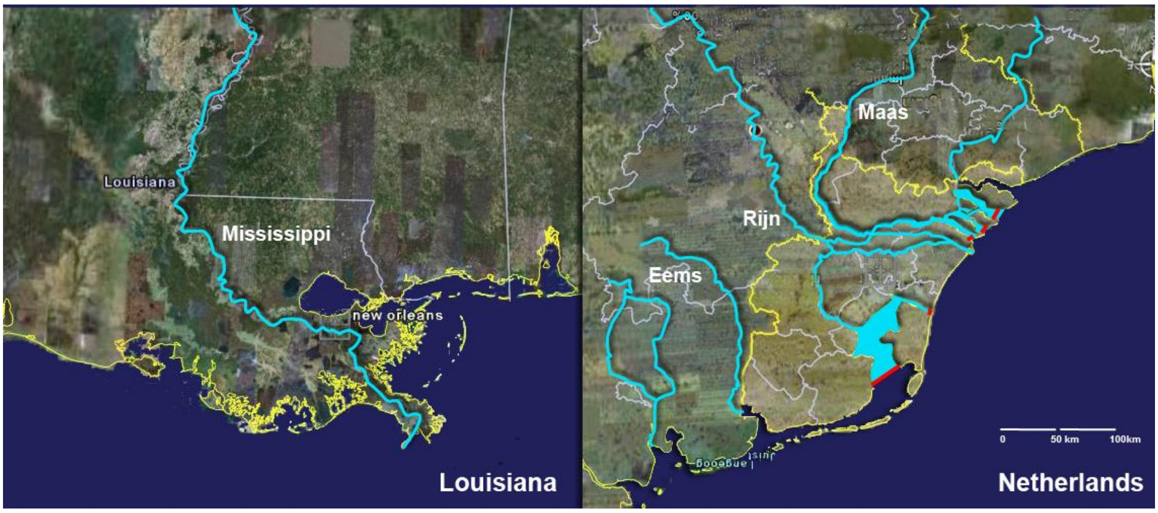


Figure 2 Mississippi Delta and the Netherlands, outlining fresh water bodies (similar scale, image of the Netherlands oriented South pointing upwards)

The search for solutions for flooding at a certain point of time is obviously dominated by the opinions and interests of landowners, business leaders and public leadership. History shows that besides providing flood protection, the development of the Dutch Delta is dominated by agriculture (marshland cultivation / fresh water economy) as the most important economic factor besides trade. Keeping out salt water was and continues to be the mainstream thinking in the low-lying Western part of the Netherlands. This eventually led to the cultivation of nearly all marshlands and closure of many estuaries (triggered by flooding disasters) and was a guiding principle in finding the response to the 1953 flood disaster as explained in The Dutch Case (see below). Doing the right thing after 1953 was based on ages of thinking and acting to cultivate the Delta, to store fresh water and to keep salt water out. The Dutch find themselves in a safe and green, yet fully man-made and managed environment.

The Dutch Case

The Netherlands Delta through the ages developed to its present state through reclamation of marshlands, increasing water management technologies and through response programs to flooding disasters. Land reclamation and water management in the Netherlands were driven by economic considerations. The first large-scale reclamations in 16th century were private initiatives to create new cultivated land and high-class land estates outside the crowded cities. The closure of the Zuiderzee protects the central part of the Netherlands against flooding, and enabled the reclamation of large formerly tidal areas for agriculture and the construction of a large fresh water basin to flush out salt water in the bordering Province of North-Holland, again for agricultural needs.

In response to the (coastal) flood disaster in 1953, the Delta Act prescribed closing off most of the last open estuaries to increase the level of flood protection and to save costs on raising

a considerable length of levees along these estuaries. It was in the 70's that a growing environmental awareness pushed the need for less drastic solutions. The main issue was whether or not to close the Eastern Scheldt Estuary and turn it into a fresh water basin. The decision was to go for a gated solution, and keep the estuary in a (semi-) natural state, which at that time was a challenging approach. Although driven by safety, the Delta Project enabled the creation of additional fresh water storage and an overall improvement of the fresh-water-management system. Only the Western Scheldt estuary was left open, this to guarantee access to the port of Antwerp (Belgium). The other salt water and intermediate estuaries, with the Eastern Scheldt estuary as the exception, were all turned into fresh water systems, effectively separating fresh and salt water systems. Although the gated barrier in the Eastern Scheldt allows tidal water in the estuary, it effectively blocks sediments, introducing a series of shoaling and erosion patterns.

However, there are no solutions without regrets. The decision to build a gated barrier in the Eastern Scheldt clearly was a compromise between the demand for flood protection and environmental considerations. The current appreciation for environmental values leads many to regret the choice for a gated solution. Today, many would prefer a flood protection system that would allow a more or totally open estuary with intact gradients between rivers and the sea.

The Mississippi Delta Case

The Mississippi River Flooding in 1927 required a new and integrated approach to protect values bordering this mighty river and its branches. New and stronger levees were built and now confine the river within defined limits. Overflow bypasses were created to relieve downstream flooding. Bayous were closed off to provide sufficient downstream navigational water depth. The overall effect is, however, that the main fresh water discharge and sediments are not laterally distributed into the marshlands but concentrated into the main river with a single outlet into deep water: the Mississippi Delta Birdfoot.

Lack of fresh water inflow and sediments, the excavation of many canals to support the oil industry, in combination with land subsidence and sea level rise caused an ongoing loss of salt and brackish marshlands and a further intrusion of salt water in what used to be intermediate or fresh water dominated areas. Restoration projects now include feeding closed bayous with Mississippi water and wetland creation with dredged materials.

3 Approach

Delta characteristics and related planning principles

Several planning principles, identified by the project team and applied in this study, were derived from the lessons learned from both the Mississippi and Dutch Delta case (see section 2.3) and from the notion that a long-term sustainable solution is required to cope with the uncertainties of sea level rise, subsidence and general transgression of the overall Mississippi Delta.

A distinction between the three elements in the so called '*layer model*' (see Appendix J), i.e. the ground layer (soil, water, flora and fauna), the networks (waterways, transportation infrastructure, civil engineering works) and occupation (living, working, recreation), is of importance to take into account differences in dynamics between these layers. In particular, the differences between these layers in the time scale for changes, which range from decades to hundreds of years, is important when considering interventions.

Related to the 'occupation layer'

A sufficient hurricane protection is required for people and values (*the occupation layer*) with an appropriate safety level, which might be different for particular areas. To allow the New Orleans society and economy to prosper again, protection from destructive sea and river flooding must be at least as high as economically possible.

A risk-based approach will have to determine which safety levels are appropriate for particular areas. This implies that the size of the flooding risk (defined as the multiplication of flood damage and the probability of such flood damage to occur) should drive decisions from an overall economic point of view. This approach may give rise to prolonged discussions about for example which costs and which benefits of flood risk reduction measures can be applied in the evaluation. This may be one of the reasons why in the US the rules and regulations about what can be taken into account in governmental flood risk reduction projects is strictly defined. These strict rules, in which for example only flood damages in the flood-prone area can be taken into account and not other damages, should in the opinion of the Dutch team not be applied in the framework of LACPR since they do not sufficiently recognize the effects of flooding in the New Orleans area on Louisiana and on the Nation as a whole.

Given the economic values at stake in the Metropolitan area of New Orleans, the highest benefits of flood risk reduction measures will involve measures that protect the urban areas. The wetland areas in the delta can play an important supporting role in providing such protection. The city of New Orleans could be considered as the hard pit in a soft fruit: the '*fruit and pit' concept*'. In this concept, the city (the 'pit') will be defended against flooding at the highest feasible safety levels. The 'fruit' is the delta with its diverse habitats and high productivity. This soft fruit protects the 'pit' and the sustainable functioning ('health') is crucial for long-term safety and the livelihood of the citizens.

Related to the 'networks layer'

As a result of the development of subsequent delta lobes, the delta is structured from upstream to downstream, and has a radial architecture. This is reflected in the existing *networks layer.* This architecture must be the leading when deciding about delta functioning in the future (for example, fresh water diversions should be located upstream), and *building with nature* is an important means to influence delta functioning.

Navigation on the Mississippi River and port activities are of paramount importance to the regional economy and in fact also for the entire Mid-West of the US. Navigation must be safeguarded and if possible improved.

Related to the 'ground layer'

The geo-morphological evolution of a delta (*the ground layer*) is marked by a spatial and temporal cycle, spanning thousands of years. Delta lobe formation and degradation is dynamic. This is of relevance when considering both the physical and the biological functioning of the delta area. By stabilizing the present status, degradation can be slowed down, and this helps to gain time for adaptation to the long-term spatial and temporal cycle (the Adaptation Principle).

A distinction should be made between active and inactive lobes. Older lobes are gradually eroding on a time scale of thousands of years. Growth and loss is part of the natural cycle. The architecture of the delta has been fixed by past interventions, while delta lobe evolution has been accelerated. Subsidence of non-active lobes can be slowed down but can not be stopped on the long run. It is logical to utilize the structuring potential of the active lobe and its tendency of natural crevassing as much as possible. Priority for inactive lobes should be on stabilization, and for active lobes on wetland formation.

Keeping, restoring and improving as much as possible the existing fresh and salt water gradients in both the Pontchartrain and Barataria basin including sediment dynamics is a condition to preserve and improve the natural system of marshlands, swamps and land bridges.

Other planning principles

Flexibility in the planning and implementation of flood risk reduction and landscape stabilization measures should be maintained and increased. One can not predict the future with much accuracy and one must accept that significant gaps in knowledge exist. Measures taken now need to be flexible and extendable in order to allow efficient and effective adaptation and mitigation in the future. A step-by-step approach in reaching the final objective, with regular updates of the original plan, is a prerequisite for final success. Experiments and pilot projects can help to reduce uncertainties. A proper phasing of interventions allows learning by doing. A flexible approach allows redesign and adaptation of measures based on increasing knowledge and experience.

Approach

The above ideas and guiding principles lead to the following main items in the approach:

1. Defend the urban areas, in particular the metropolitan area of New Orleans. For the short term, this implies relying on levees and possibly other structures. Landscape stabilization measures, that possibly can contribute to flood risk reduction, generally need more time to mature.

2. In order to maintain flexibility, the use of measures that are relatively easy to adapt or changed in the future is preferred in favor of measures that are difficult to change.

3. Keep the natural system in place and avoid obstructing natural upstream-downstream pathways of water, sediment, nutrients and species. Maintain natural creek patterns and density. Increase the supply of fresh water and nutrients gradually to prevent ecological shocks. Allow and provide space for the relocation of oyster cultures.

4. Strengthen natural processes for restoration and enhanced safety. Acknowledge the effectiveness of marshlands to reduce wave heights and to reduce storm surges. Expedite marshland maintenance and marshland building to compensate the loss of marshlands in recent history and further enhance flood protection. Use the active lobe for marshland expansion, stabilization and maintenance. Attempt to delay the deterioration of inactive delta lobes.

5. Consider relocating the river mouth by decoupling the Birdfoot and utilizing the sediment for levee construction and marshland creation. This implies dredging large volumes and conveying dredged material over long distances. Use the Mississippi River sediment supply to enhance near-shore suspended sediment concentrations and the sediment budget for the coastal area.

Criteria for evaluation

The overall objective of the project is to draft a plan for the long-term flood risk reduction and landscape stabilization of part of coastal Louisiana, which possibly also enhances the local and regional economy. Landscape stabilization is the strengthening of the natural functioning of the ecosystem, for example by reintroduction of natural gradients, by improving the sediment balance and by increasing biodiversity.

The plan consists of a set of measures that lead to flood risk reduction and landscape stabilization, and which enable economic development. To measure the effect of measures, criteria for evaluation are applied. Which criteria to use follows from the overall objective of the project.

In this project the overall objective is detailed in the following five main objectives:

1. Increase in flood safety. This increase is expressed in the flood risk reduction for urban and for rural areas.
2. A more sustainable Delta, which in the case of the project means:
   a) improvement of the overall sediment balance;
   b) improvement in salinity gradients;
   c) improvements in ecosystem functioning; and
   d) improvements in the nutrients balance.
3. Retain and develop socio-economic values, i.e. navigation and other economic activities, historical values and social and cultural values.
4. High feasibility of measures, which in the case of the project means:
   a) The amount of time required for the implementation of measures. For some measures also time to maturation [1)] needs to be considered.
   b) High technical feasibility of the measures including maintenance and robustness.
   c) High flexibility in measures including adaptability and separability.
   d) High public support for measures.
5. Low costs for investments and for maintenance.

The balance of pros and cons for each alternative will be presented with these five main objectives (*second phase of the project*). If necessary, also the relevant subcriteria will be addressed. It is emphasized that these objectives will obtain different weights in the decision making about alternatives. At this stage all objectives are assumed to have a similar weight. These criteria are used for the screening of measures and for the evaluation of the alternatives. Most of these criteria will be evaluated qualitatively by expert judgment. See Appendix A for more details.

[1]) Time to maturation is defined as the time period between investments are made to implement a measure and the moment that benefits are realized; for example in case of river diversions to stimulate wetland development.

4 Possible measures

The Dutch team made an inventory of possible (and perhaps impossible) measures to either reduce flood risks directly by levees and other engineered features and/or reduce flood risks indirectly by consolidating, restoring or changing the overall dynamics of the delta and in particular that of marshlands, swamps and the Birdfoot. Non-structural measures are not addressed, partly because some important types of non-structural measures are already in place (flood warning, evacuation procedures), while other types (like flood proofing of houses and industries) are deemed to be very local and therefore with a rather limited potential to increase risk reduction for the large New Orleans Metropolitan Area

The preliminary plans by both LACPR and the State of Louisiana identified a large number of measures to achieve the objectives adopted for the planning. The Dutch team reviewed these measures in a number of workshops held in the Netherlands trying to understand their intentions and effects. From an overall perspective, there seems to be a broad consensus on what measures might be appropriate to at least achieve a part of the objectives. For the sake of comparison and eventually selection, the various measures identified and reviewed by the team in Planning Area 1 and 2 are grouped into five categories, which differ in time scale, effect and intention. Flood risk reduction is the main point of entry for this grouping:

1. Direct protection of incorporated values;
2. Closed basin hurricane surge protection;
3. Measures to consolidate and increase present natural surge reduction;
4. Basin surge reduction measures; and
5. System Interventions for long-term natural surge reduction.

Measures in groups 1) and 2) are engineered structures that, by definition, provide risk reduction to a pre-determined level, while the other (landscape stabilization type) measures are designed to reduce hurricane surges and are evaluated in terms of their contribution to risk reduction, both in a short-term and long-term perspective. Landscape stabilization in this grouping is considered to be a part of a multiple lines of defense strategy.

Other important objectives of Landscape Stabilization (healthy marshlands) such as reducing the nutrient load into the Gulf of Mexico are not addressed in this phase, but will be evaluated in the impact matrices in phase 2.

(1) Direct Protection of Incorporated Values

This group of measures aims to protect concentrated values within the Delta with a surrounding protection system (Figure 3). This is in line with the basic idea behind the present situation, where levee rings protect built-up areas from sea and river flooding. Basically, there are two groups of alternatives: (1) upgrading and completing the present levee and floodwall alignments and (2) adopting a new design and alignment to provide the appropriate level of protection.

The alignments chosen for evaluation are close to the alignments of the present (repaired and upgraded) system. Existing plans to close the three drainage canals in New Orleans, to gate the Industrial Canal and the Gulf Intracoastal Waterway (GIWW) are considered to be included and the Dutch team assumes that the designs will be based on an appropriate protection level.
For a better protection of New Orleans Lake Front the Dutch team suggests to consider a new levee alignment in front of the existing one a few hundred meters in the Lake as an alternative. Such a new levee, with gates to allow the outflow of pumped drainage water during normal conditions, would avoid upgrading the space-confined existing waterfront and would allow for a temporary storage of pumped drainage water in the water area protected by the new levee, and would avoid severe wave attack on more vulnerable structures outside the existing levee.

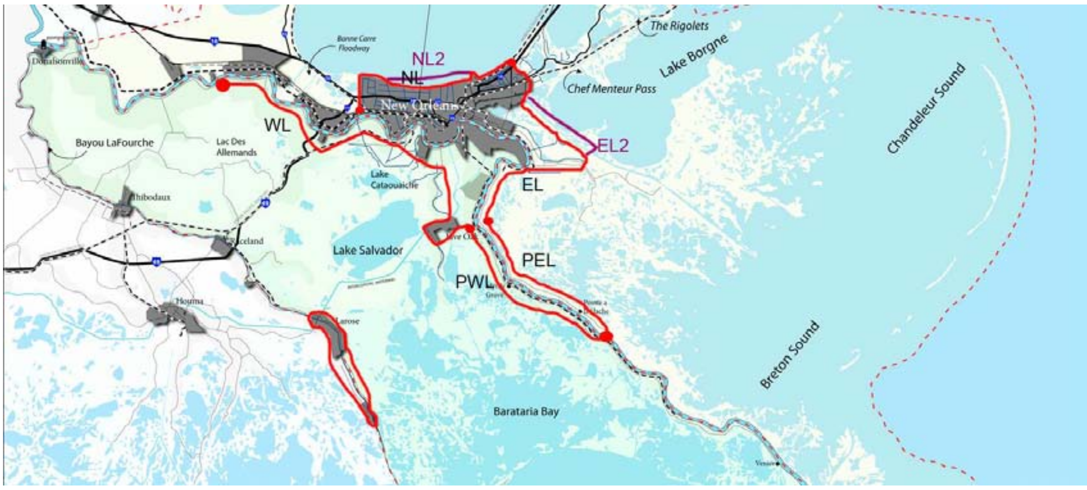


Figure 3 Alternative alignments for levee systems protecting New Orleans and part of the Plaquemines

Another important consideration is whether or not to close the Mississippi River Gulf Outlet (MRGO) for navigation. The Dutch team feels that both alternatives need further analysis. The canal is used scarcely (on average about one ship per day), maintenance is expensive and it passes vulnerable marshlands, but it still could be a significant contribution to the overall logistic chain.

Levees and gates are, in principle, and from a strategic planning point of view, simple engineered structures that can be build in a relatively short time. They provide immediate protection after completion. From an engineering and construction point of view these structures are complicated and challenging projects.

(2) Closed Basin Hurricane Surge Protection

These alternative measures basically are features to close off either or both Pontchartrain and Barataria basins during a hurricane threat. They prevent hurricane surges to penetrate the basins. Implementing this protection system would partly avoid upgrading the existing systems and might be an economical solution if proven to be effective.

Lake Pontchartrain Gated Levee Barrier

Hurricane Katrina caused a surge in water levels in Lake Pontchartrain since large amounts of water rushed over the land bridge from Lake Borgne into Lake Pontchartrain and through the Chef Menteur and Rigolets passes raising the lake water level with some 6 feet. On top of that, a significant set-up of the water level on the Lake itself occurred because the hurricane-force winds pushed the water towards the Lake Front area. A Lake Pontchartrain barrier scheme (Figure 4) will prevent the surge in water level but cannot avoid a significant wind set-up on the lake itself. *Whether or not this needs to be a fully closed system or a system of levees with permanent openings at the two passes is still an open question. Further hydraulic analysis in the second phase of the project will clarify this issue*.

A barrier scheme was already investigated in the 1960's but then rejected for environmental and other reasons. Closing off Lake Pontchartrain with a barrier is an alternative for upgrading New Orleans lake front and will also provide protection to Slidell and other areas bordering the Lake. LACPR indicates various alignments. Two alignments were selected for further consideration, one along the I10 and one along the C90 highway.

Barataria Basin Gated Levee Barrier

Closing off Barataria basin (Figure 4) seems to be an obvious and effective measure to provide protection to the upper part of the basin. It would avoid construction and/or upgrading levees along the borders of the basin and around isolated values. LACPR indicates an alignment following that of the GIWW. This is an obvious choice. The Waterway is an excellent route supporting construction and can already be regarded as a hydrological and ecological barrier splitting up the basin. The barrier, and in particular the gates provided in it, would allow for a better water control (to prevent salt intrusion, for instance) but will undoubtedly further change the basin into a human-controlled environment instead of an open estuary system.

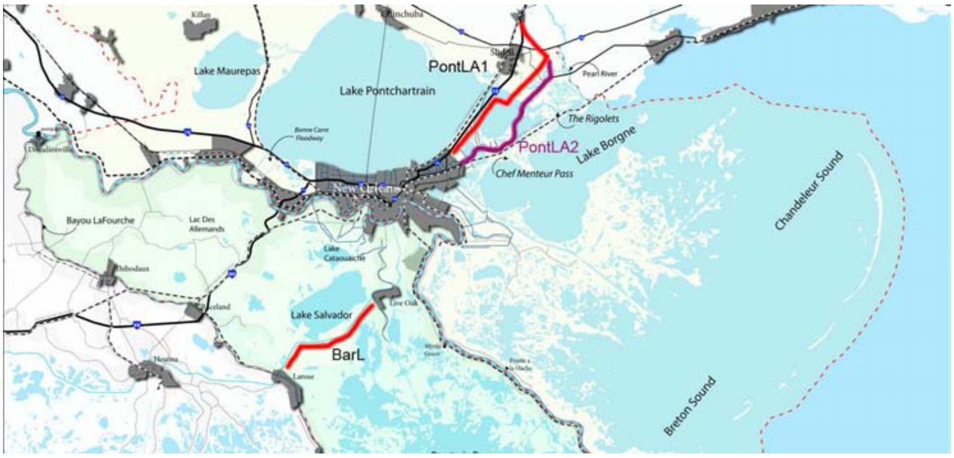


Figure 4   Alternative alignments for levees systems in the Pontchartrain and Barataria Basins

From a technical point of view, gated levee barriers are proven structures applied in the Netherlands and elsewhere in the world. Although scale and logistic conditions are unprecedented, the scheme is most probably within the present state-of-the-art and could be implemented within a reasonable time frame. However, the impact on the overall basin dynamics in terms of water, sediments and ecology are difficult to predict and the scheme probably needs extensive compensation efforts to mitigate effects.

(3) Measures to Consolidate and Increase Present Natural Surge Reduction

Healthy marshlands and swamps to a certain extent reduce hurricane surges and absorb a significant portion of the (surge and wave) energy generated by the passing wind fields. The general notion is that degrading marshlands and vanished swamps contributed to Katrina's detrimental effects and that consolidating and restoring natural protection must be an essential part of the overall protection plan. Such measures would not only contribute to a reduction of flood risks, but would also address concerns about the health and integrity of the ecosystem.

Considering the geo-morphological evolution of the delta, increased (upstream and lateral) diversion of fresh river water and in particular fine sediments into the basins are the key factors in landscape stabilization. However, restoring the basins to a more healthier system requires a combination of measures to, at least, simulate the natural dynamics of an open system. Existing fresh water diversions prove to be effective in consolidating certain areas from a water quality point of view (to prevent further salt water intrusion) but up to now fail to build-up new marshlands. Present structures divert water and not (enough) sediments. For a significant risk reduction, large and continuous marshlands (many miles with as little canals as possible) and swamps are needed to reduce storm surge heights. There are many ideas on what type of measures are required to achieve the overall objectives, but unfortunately little reported experience. The following measures are included in the evaluation:

Mississippi Fresh Water Diversions

The lack of (external) nutrient-rich freshwater supply in the Pontchartrain and Barataria basin is one of the main reasons for increased salt-water intrusion and consequent deterioration of the typical freshwater cypress swamps. Additional diversions are probably required to balance further intrusion and balance general subsidence. The ideal or achievable distribution of Mississippi water over the main stem and into the basins considering human needs, navigation, ecology and other factors is not a simple analysis and most probably a matter of compromise. And yet this distribution is a conditional factor for all ideas and plans to stabilize and restore the natural landscape. Considering the total capacity of the existing diversion works compared to the average river discharge, additional diversions seem to be feasible and hence are part of the plan.

Marshland Stabilization

Marshland Stabilization aims to consolidate existing marshes by filling or closing the network of canals as much as possible to stop further erosion and to reduce salt water intrusion through this network of open water. The degradation of (still) existing salt water and intermediate marshlands, in which marshlands turn into open water, is an irreversible process that is to a large extent caused by internal erosion as a result of canal dredging. Considering the urgency and necessary scale of operation, innovative solutions to realize marshland stabilization in a reasonable time and against reasonable costs are required. This calls for the development of dedicated equipment and most certainly new and dedicated working methods. Marshland stabilization is considered a backbone measure that needs to be implemented as a matter of priority.

Marshland/Swamp Creation

Marshland creation aims to turn open water back into fresh water swamps. By nature, marshes and swamps are 'created' by a combination of nutrient-rich freshwater, fine sediments and vegetation. Essentially, there are three methods to turn (shallow) open water into marshland:

1. By simulating (and accelerating) natural processes through water and sediment diversions from the Mississippi river into designated areas. Either by constructing new diversion works (capable of diverting sufficient sediments) or by creating 'natural' overflows along the riverbank at certain locations to simulate flooding events and stimulate crevasse building. Both techniques are applied in the Mississippi Delta. These methods would serve a long-term strategy to create a sequence of new freshwater marsh areas from upstream to downstream along the Mississippi ridge.
2. Filling shallow open water with piped sediments to create new wetlands as a basis for the growth of vegetation. A number of projects were executed in the Mississippi Delta by USACE under the program for 'Beneficial Use of Dredged Materials'. The continuous supply of nutrient-rich freshwater is obviously required to build up freshwater vegetation. The process of filling can be very fast, depending on the equipment employed and availability of sediments.
3. The construction of Marshland polders to serve accelerated growth of vegetation without the initial supply of large quantities of piped sediments. The idea builds on the methods of land reclamation in the Netherlands to create agricultural lands. The first step is to enclose a designated shallow water area with levees, after which the inside water table is lowered to a level at or just above the bottom to allow vegetation to grow. Depending on the size of the polder, simple, even wind-driven pumps could be used. The initial vegetation in the polder serves as a starting point to build up organic sediments. The second step is to gradually increase the polder's water table to stimulate growth and receive and trap fine sediments either through a diversion work or through temporary injections of fine sediments with dredging equipment. The third and last step is to reinstate 'natural' open connections with surrounding water by removing parts of the enclosure levees. In the Netherlands, polder marshlands were created unintentionally but now are among the richest (and protected) environmental areas in Europe.

A combination of methods could indeed create significant areas of new marshlands in the Delta although it would take a number of decades to do so. In the Netherlands, some 150,000 hectares of land was reclaimed in a period between 1930 and 1960, serving the fresh water economy. Louisiana in principle could do the same serving its marshland ecology and estuarine economy.

The overall target (at least for this evaluation and preliminary costing purposes) is to apply up to 20% of the annual Mississippi sediment load for Marshland/Swamp Creation in the Pontchartrain and Barataria basins. It is recognized that upstream marshland creation using Mississippi sediments will ultimately lead to an increased erosion of the Birdfoot.

Marshland Protection

Marshland protection measures aim to reduce wave (and hurricane) attack from the Gulf on the salt-water marsh areas bordering the seashore. Natural barrier islands still protect the Barataria basin but are more or less vanished in the Pontchartrain basin. In principle, there is a number of options to reinstate a string of barrier islands in front of both basins using high capacity dredging equipment. Similar large-scale dredging projects (be it for different purposes) are currently executed in Dubai and other places involving the handling of up to 1 billion of m^3 of sediments in a few years for a reasonable price.

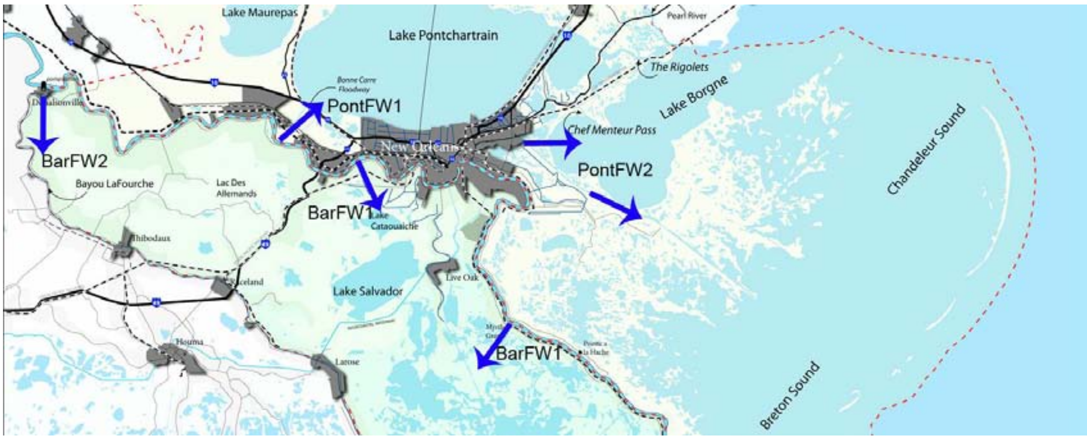


Figure 5 Fresh water diversion measures

(4) Basin Surge Reduction Measures

The purpose of these measures is to limit the effect of hurricane surges entering the basins by adsorbing its energy either through reshaping the existing outer barrier islands or through creating a new string of man-made levees (ridges) inside the Pontchartrain and Barataria basin. Figure 6 indicates possible alignments.

This surge-reduction barrier consists of what the project team has started to call 'eco-levees'. These levees are unlike traditional (US and Dutch) levees and are marked by very gentle slopes on both sides and a wide footprint They are intended to be built from locally available materials with a sufficiently large cross-section to deal with slope erosion and wave overtopping in extreme conditions The purpose is not to 'stop' the hurricane surge, but to reduce the surge and waves to an 'acceptable' level behind it. The system obviously requires sufficient space to receive and store overtopping surges and a secondary levee system to prevent flooding of protected values. Damage and erosion after an extreme event of course will have to be repaired. This may require a significant management and maintenance effort. Lacking special armoring on slopes and crest, it is relatively easy (and cheap) to heighten the eco-levee when required in case of further subsidence and/or higher surge levels.

The eco-levee barrier is not a continuous levee over many miles, but has openings for existing natural and man made channels and canals.). Hence, the natural flow of water and migration of species is essentially unobstructed.

Another way to interpret the eco-levee is to consider it as a natural ridge, comparable to the ridges that are found on many places along the rivers in the delta. The French Quarter, for example, was built on such a ridge. The big difference with natural ridges is that the eco-levees are positioned essentially perpendicular to the waterways and more or less parallel to the coast.

The design of an eco-levee is based on the following concepts:

- Apply gentle slopes to avoid expensive subsoil improvements (drained solutions).
- Use local sediments (silt) as much as possible.
- Apply a design that can safely deal with overflow and overtopping waves, this in order to reduce crest height.
- Include landscaped surge-buffering zones

Depending on crest height, the levee footprint including buffering is in within 500 to 750 meter range. The existing levee and floodwall system is considered to be a secondary system and will be a part of the buffering zone.

The overall system (crest height, spacing and openings) must be carefully sized in order to create a sufficiently large reduction of a hurricane surge and to prevent system failure by progressive erosion during a hurricane attack in particular in and around the openings. *Verification of the hurricane reduction potential is proposed through a number of simulations in the 2nd phase of this study.*

Figure 6 Basin surge reduction measures

Another type of measures that fits this group is the development of new barrier islands along the outer rim of the marshland (see Figure 6). These islands could be reshaped (raised and extended) to significantly contribute to hurricane-surge reduction, similar to the above explained eco-levee concept. In this context, to compensate for the loss of the Chandeleur barrier islands as marshland protection in the Pontchartrain basin, an alternative option is to create the conditions for the building of beach barriers by natural processes (wave action). Comparable to shoreface nourishment, a subtidal plateau of dredged material could be put in place, which will lead to natural barrier buildup by wave action. This plateau could be optimized to provide large scale habitat for oyster beds.

(5) System Interventions for Long Term Natural Surge Reduction

The final group of flood risk reduction measures consists of options for large-scale interventions in the Mississippi Birdfoot (see Figure 7, Figure 8, and Figure 9). The idea is to reduce (stop) the current wastage of sediment resources, which are now to a large extent dumped in the depths of the Gulf of Mexico.
Reducing current wastage of sediment resources can be realized by *large-scale crevasse building measures*. Alternatively, dredging large-scale openings in one or both banks of the Mississippi River downstream of Pointe à La Hache can do this; the main flow of the river can be diverted. Hence, the freshwater and sediments conveyed by the river would stay in the near-shore area, and sediments could settle downstream in the marshland area. Such sediment deposition is not only the result of the flow of river water, but the tidal flows and wave action contribute to the redistribution of sediments. Natural processes would be used in this way to build marshland, which helps to reduce hurricane surges. In essence, this measure would imply to '*give up the Birdfoot*'.

It goes without saying that navigation interests must be safeguarded at all times. River navigation is too important for the region and the Nation to allow compromises.

The project team identified several options for this measure:

- By dredging a wide (5 km), relatively shallow (5 m) opening in the West bank of the river. River navigation would continue to use the existing navigation channel.
- By dredging relatively narrow (1 km) but deep (15 – 20 m) channels on both the East and West bank of the river. These new channels would be the access channel for ocean going navigation to reach the Mississippi River. In this alternative, the existing Birdfoot would no longer be maintained and would eventually – after a long decay process – disappear, while its sediments would benefit the coastal zone.

Figure 7 Marshland creation using crevasse splays and technical measures in the active lobe and near New Orleans

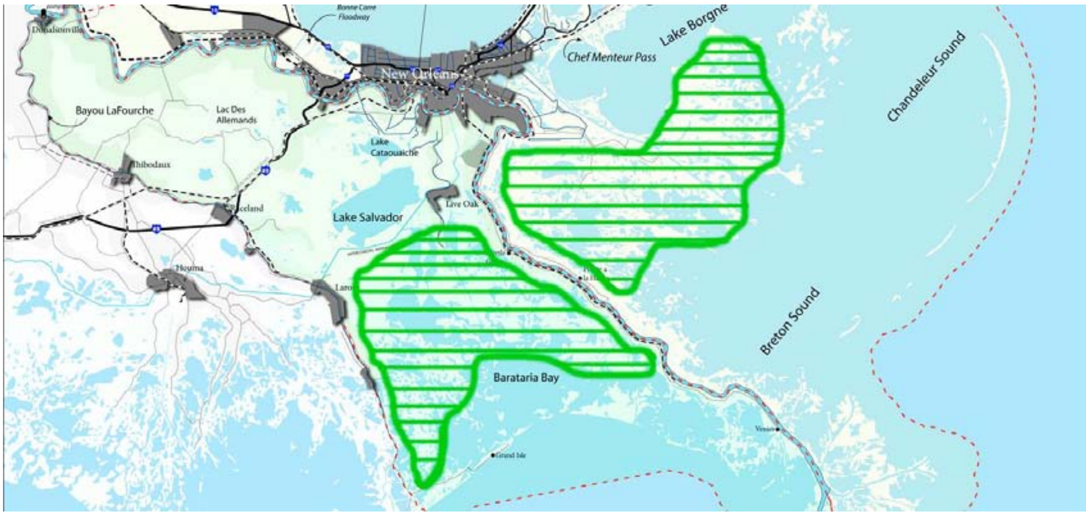


Figure 8 Marshland stabilization measures in both lobes

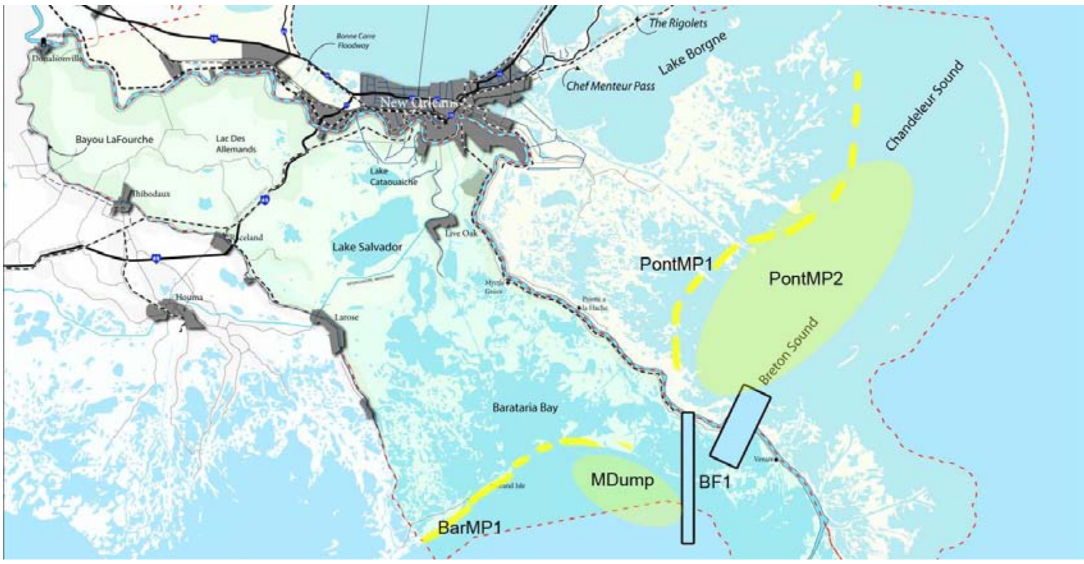


Figure 9 Marshland protection measures and large-scale interventions

5 Alternative strategies

The main purpose of the planning process is to find to best set of measures to reach the overall objectives for flood risk reduction and landscape stabilization, possibly enhancing the local and regional economy.

To focus evaluations and recommendations, the project team designed three alternative strategies that differ significantly in overall effect. These strategies are shaped on what the Dutch team considers to be the most important planning decision for the future of the Mississippi Delta; whether or not to close off the basins with (gated) barriers and change the present (natural) state into managed land and water.

The three strategic alternatives for both the Pontchartrain and Barataria basins are therefore formulated according to this key planning principle:
1. Open Estuary System (three variants)
2. Semi Open Defense System
3. Closed Defense System

From a strategic point of view, protecting incorporated values against hurricane surges by means of surrounding levees and floodwalls is an accepted and effective way of flood risk reduction and the system might be enhanced to cope with more extreme events to provide an adequate protection level. These are proven measures that, in principle, could be implemented in a relatively short time period (set aside budget and land ownership complications) and would serve to be the primary protection.

Landscape stabilization is a secondary but important means to add sustained safety in the long term, thus introducing the multiple lines of defense principle. The ‘open’ system for the long term relies heavily on the effectiveness of landscape measures that are (probably) complicated and difficult to plan and implement. Can the Mississippi Delta be restored to both serve ecology and safety? Intensive research and pilot projects are required to start finding effective and economic solutions for large-scale restorations. A ‘closed’ defense system avoids being reliant on landscape stabilization for risk reduction purposes and provides safety for a large area behind it. However, even equipped with gates to pass water, the structure will be a definite morphological and ecological barrier separating the basins into a fresh and saltwater area thereby loosing (some) of its important intermediate areas. The ‘Semi Open Defense System’ obviously tries to combine the better of the two extremes, but requires innovative solutions to achieve the goals of risk reduction.

Each strategy consist of (1) a set of measures for a safe city and (2) a second set of measures for aimed at realizing a sustainable delta. Schematically, the alternative strategies are outlined in Figure 10. Which measures are part of each strategy is detailed in Appendix G.

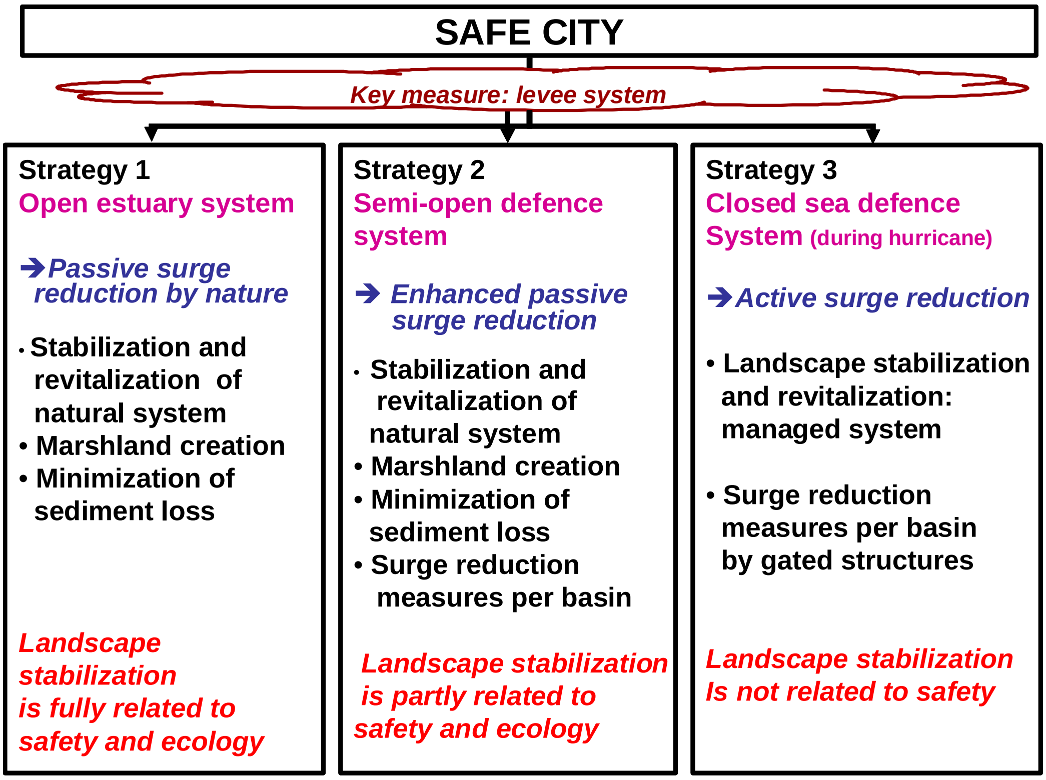


Figure 10 Overview of main characteristics of alternative strategies for flood risk reduction and landscape stabilization

For a safe city the main question whether to rely on upgrading the existing levees or building new levees (or a combination of these two options). At this stage, an open question is whether or not a gate in the Mississippi river is feasible.

As mentioned, to achieve a sustainable delta three strategies were identified: an Open Estuary System (three variants), a Semi Open Defense System and a Closed Defense System. Each strategy will lead to a different height of the levees required for a safe city, since the level of surge reduction differs between the strategies. For example, with a closed defense system the heights of the levees in the city of New Orleans can be lower than with an open defense system to realize the same flood protection level. (*This will be worked out in the second phase of the project*).

Impact assessment: to be detailed in the second phase of the project.

6 Management and maintenance

First draft only (see Appendix I for details)

Strategic and tactical goals

From the viewpoint of management and maintenance the strategic and tactical goals of the flood protection scheme need to be interlinked. The Dutch concept of safety assessment (every 5 years) including the risk assessment (every 25 to 50 years) can easily be transferred to the proposed strategies for the Louisiana coast and the New Orleans area.

The strategic goals of the project are flood risk reduction and landscape stabilization in order to enable socio-economic developments. It must be realized that these goals cannot be reached in a short period of time. It is fair to say that it will take decades (30-50 years) to reach realistic goals. This inevitably leads to the conclusion that during that period the strategic goals may already have to be adapted once or twice. This is an important aspect in developing the management and maintenance strategy.

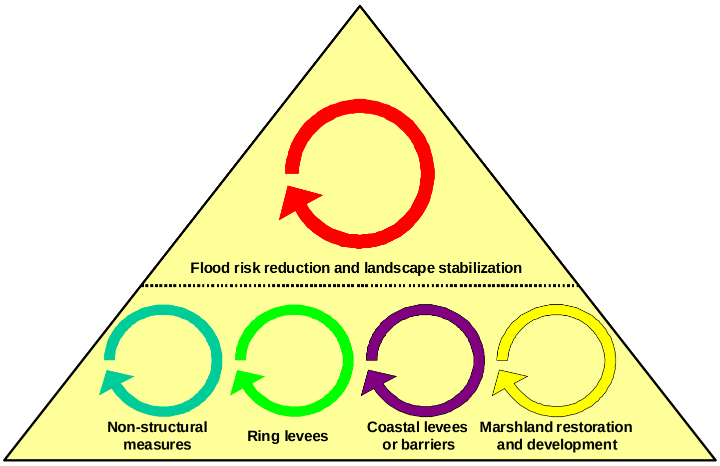


Figure 11 Strategic and tactical planning

The strategic goals are accomplished by the various types of proposed measures. Each of these groups of measures has specific characteristics.

The ring levees are meant to protect metropolitan areas from flooding. Depending on the required safety level (ranging from 10^{-5} to 10^{-2} per year) (re-)construction of these embankments with a total length of several hundred kilometers will take approximately 5 years depending on the available budget. These measures can be described as no-regret measures to be implemented at short term. The planning period for these levees should be between 50 and 200 years, depending on the type of structures applied. Structures that can easily be adapted can be designed using a short planning period, whereas the longer planning periods are required for (elements of the) structures that cannot be adapted easily.

The coastal levees and/or barriers probably will take more time to design because the uncertainties in the performance and/or the complexity of the design. Probably it will take a number of years to come up with a design that fits the strategic goals of the scheme. During this research and design period a number of large scale pilot projects can be tested in practice.

The marshland restoration and development is a long-term measure. It will take decades to ‘create’ significant developments. Also, the uncertainties attached to these measures are greater than for the coastal levees and/or barriers. Large-scale tests in the field of these measures are required.

The tactical goals for the various measures need to be projected on the strategic time span of roughly 50 years. The combined effect of these measures changes over time (except for the non-structural measures).

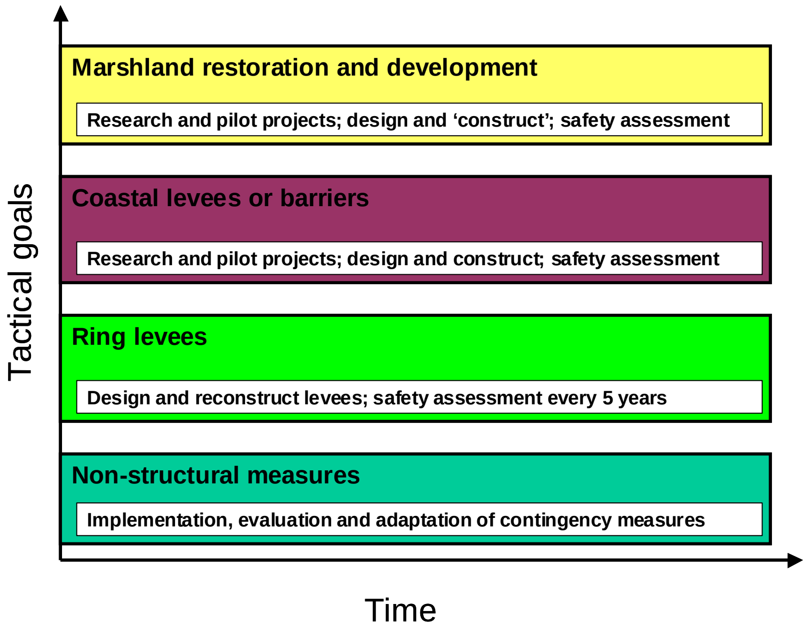


Figure 12 Tactical planning elements

After construction, the ring levees will slowly deteriorate due to the combined effect of sea level rise and settlement / subsidence. That effect can be compensated once the measures ‘coastal levees’ or ‘marshland restoration and development’ start to bear fruit. This requires assessing the actual performance of the various measures regularly. For the levees a 5 year period is considered to be adequate.

Operational goals

From the tactical goals the operational goals for management and maintenance can be derived. (*to be elaborated*)

Integration and coordination

The multiple line of defense approach is only as robust as the quality of managing and maintaining the individual lines. The need for integrating and coordinating the activities of the various authorities involved is evident.

The key issue related to management and maintenance is to find a suitable balance between the role and actions of the various authorities involved. This research project is not aimed at the organization of governmental organizations. However, based on European and American experience a number of relevant criteria for the optimal management and maintenance situation can be derived.

1. appropriate planning level;
2. local authority;
3. spatial and functional integration; and
4. clear responsibilities.

The first two criteria seem to be contradictory. It is necessary to have a planning level that matches the scale of the natural system and the processes that take place. For example, the Mississippi River and the coast of the Gulf of Mexico need to be treated as a whole. On the other hand, flood protection measures need to be taken at the lowest level possible in order to keep local authorities involved and committed to their tasks. The local authorities are able to commit local residents to the project and to find optimal solutions based on costs and benefits of flood protection measures.

The third criterion is based the ability to integrate the various functional demands in a spatial framework.

The fourth criterion is a clear separation of responsibilities including the need for checks and balances.

A number of sub-criteria can be developed from these four criteria:

1. adequate planning level:
   a) planning based on the natural systems involved, i.e. the river and the coastal system;
   b) planning based on functions assigned to these systems such as flood protection, navigation, etc.;
2. local authority:
   a) legislation, which gives (local) water authorities the authority to carry out their duties, to raise funds and to enforce their rights;
   b) taxation of the people in the jurisdiction area of the water authority for generating income to carry out its duties;
   c) representation of stakeholders in the water authorities, to create stakeholder commitment and to ensure democratic decision-making;
   d) funding of large capital for major investments, which is mainly found within the private sector;
   e) institutional development, addressing trained staff and tools such as accurate cadastral and financial administrations, needed to allow for effective and efficient operation;
3. spatial and functional integration:
   a) functional integration;

b) spatial integration;
4. clear responsibilities, including checks and balances.

Recommended situation

Based on the criteria the recommended situation for management and maintenance of the future flood protection scheme in the greater New Orleans area can be described as follows:

- political commitment to strategic management goals and the framework for tactical management goals and measures;
- designing and implementing the specific tactical measures within the approved framework;
- regular update of tactical planning (once every 1-5 years, depending on the type of measures); and
- funding for operational management and maintenance.

Given the responsibilities of various authorities involved it seems to be required to discern two interlinked ‘chains of command’, leading to both federal and state government.

Item	Authority	Responsibilities
Integration/coordination	State	Risk management
Safe city	Levee board	M&M ring levee
Coastal management	USACE/State	M&M coastline
Coastal levees/barriers	USACE	M&M levees/barriers
Birdfoot/river management	USACE	River management
Non-structural measures	Parish / State	Spatial planning

7 Conclusions and recommendations

Tentatively, the Dutch team has reached the conclusions and recommendations presented in this chapter. Note that this is a work in progress ! The second phase of the project will provide back-up of these conclusions / recommendations.

The current formulation of conclusions and recommendation lacks reference to the appendix section in which the groundwork for a particular conclusion or recommendation is laid.

Tentative conclusions

Conclusions regarding flood protection

1. Whatever level of flood protection is provided, it can not provide *full* flood protection, in which never in the future there would be any flood damage. Higher investments in flood protection measures mean more safety, bur some flood risk will always remain. A tentative Cost/Benefit analysis suggests that a substantial increase of the flood protection level of the metropolitan area of New Orleans is economically justified.

2. The Dutch principles applied in the planning for sea defense (close estuaries; short sea defense) is <u>not</u> to be considered as an obvious and proven solution for the Mississippi Delta.

3. The decision whether to develop a fully closed coastal flood protection scheme, which will close-off the Pontchartrain and Barataria basins, is a key-decision in the overall LACPR planning effort.

4. Marshlands are effective for hurricane surge and wave reduction, but locally surge levels may increase. The effectiveness of wetlands in surge reduction depends on the spatial dimension relative to path and speed of the hurricane passing and the type of marshland. If a reduction of the surge levels due to the marshlands is taken into account in designing the flood protection system, the marshes become an essential part of the protection system and need to be maintained to ensure the level of protection in the future. However, healthy and extensive marshlands have not protected New Orleans from flooding during historic hurricane events. Marshlands can only be a part of a flood protection system for New Orleans.

Conclusions regarding ecosystem functioning

1. The ecosystem that exists today is part of a natural long-term cycle, driven by formation and degradation of active and passive Mississippi lobes. Each development stage has unique and valuable ecological values. When identifying suitable measures this must be taken into account.

2. Marshland loss rates are slowing down according to some authors (USACE, Dunbar, 1992). Good quality marshlands are able to maintain accretion speeds between 0.5 and 1.3 cm/yr, depending on flooding regime and sediment availability.

3. Sea food production in the lower Mississippi Delta is an important part of Louisiana's economy and part of what may be considered to be a cultural heritage. Good quality wetlands and in particular fresh and salt water gradients are conditional to a diverse and productive eco-system and therefore conditional to a sustainable aquatic delta economy. This aspect must be considered when deciding about a flood risk reduction and landscape stabilization strategy.

4. Safeguarding the delta ecosystem depends on restoring connections and gradients between the rivers and the coastal zone.

Conclusions regarding the design of measures

1. Available Mississippi sediment load has been reduced with a factor of 3 to 4 during the last century. Measures concerning the long-term ecosystem stabilization and restoration have to fit within this load. The amount of sediment is not large enough to recreate marshlands in all inactive lobes in the delta area.

2. It is therefore considered logical to focus on marshland stabilization on the inactive Barataria lobe, thereby safeguarding present biodiversity and productivity, and to focus on marshland creation in the active Mississippi lobe utilizing phased small-scale crevassing schemes and the principle of 'firehosing', which means that the foci of deposition of sediment will shift around with time.

3. The project team anticipates that the further reduction of marshland loss can be realized by large-scale restoration of patched marshlands (especially by closing of channels) and restoration of unimpeded freshwater flow from the river to the delta, flooding regimes and sediment availability. Priority areas will be the freshwater marshlands surrounding New Orleans.

4. A step-by-step small-scale approach for wetland and coastal restoration is recommended, starting upstream, in the vicinity of New Orleans, supported by field (and laboratory) experiments aimed at reducing uncertainties (learning by doing).

5. The option to divert the Mississippi River by means of a relatively narrow and deep channel but sufficiently large to accommodate the navigation flow on the river seems promising with regards to sedimentation issues *(this has to be analyzed in more detail in the second part of the project)*. A large, shallow diversions in the lowest parts of the Mississippi (5 km wide, 5 m deep) proves less effective for wetland restoration and the overall effect on the ecosystem is beyond predictability. Moreover, this measure will have a large impact on the navigability of the Mississippi and could introduce a substantial maintenance dredging liability.

6. Considering a levee design that can safely deal with wave overtopping and/or surge overflow with a buffering zone behind it is recommended. This in order to limit the required height of the levees while maintaining safety. This approach is now being considered for some critical levee systems in the Netherlands.

7. Given the number of options available, three distinctly different strategies can be developed, i.e. an open, semi closed, and fully closed system. This implies that in de decision process real and fundamental choices can be made.

Recommendations / pilot projects

Regarding the effects of measures or the performance of possible structures, many uncertainties and gaps in knowledge play a role at this stage of the planning process. The Dutch team suggests to use pilot studies and experiments as a means to reduce uncertainties, and suggest to consider the options described in this section.

- **Eco-Levee (Ridge Levee) pilot**. A new type of gradual slope, hydraulic fill, vegetated, ridge-like levee has been proposed in this project to be constructed in order to reduce storm surge levels in the area protected by this levee. This levee must have a sufficiently wide crest and inner slopes must be sufficiently gentle to deal with overflow during and overtopped waves during extreme events. The eco-levee may be damaged during extreme events, but total failure must be avoided. In order to explore the uncertainties of construction method (including uncertainties about the management and maintenance effort that will be required), characteristics of soils, long-term stability and the development of vegetation a pilot study is needed in which a section (say half a mile in length) is actually constructed. An option would be to set-up a USACE – Rijkswaterstaat team that drafts a detailed design and selects suitable locations, scale and techniques for construction and monitoring.
-

Figure 13 Recent field test in the Netherlands on the impact of overtopping waves on an existing levee.

Recent field tests in the Netherlands with a new device [2)] to simulate wave overtopping (see Figure 13) could be carried out on this pilot levee to simulate overflow and wave overtopping and to carry out an actual test on erosion characteristics. This experiment can be extended to also include overflow. For the location of this experiment, the project team suggests to consider the 'funnel' formed by MRGO and the GIWW, possibly just in open water of lake Borgne, at some distance from the existing shore-line.

- **Channel infilling pilot**. A pilot is proposed to develop efficient techniques to fill or plug channels. In itself, plugging a canal or filling it in over its full length is not particularly challenging from an engineering point of view. However, the number of canals involved, and the scale of the area, suggests a thorough rethinking of the existing

2) *Copyrighted design: Dr. J. van der Meer, Infram, Netherlands*

techniques to realize such plugging or filling of canals. A pilot project in which new methods and techniques are tested in the field is suggested before large scale implementation is started.

The objective of the following pilots is to find promising approaches to marsh restoration that are relatively cheap and produce a self sustaining marsh in the foreseeable future. Requirement for these pilots is that actual and future subsidence rates are low enough to allow sustainable marsh existence by natural or somewhat enhanced growth rates.

- **Accelerated natural fresh water marshland development pilot**. It is hypothesized that a temporary artificial lowering of the water level to optimal depths for marshland growth will kick-start the recovery of lost fresh water marshes (either using the remaining seed banks, or by means of artificial seeding or planting). A yearly cycle of flooding with (if needed with sediment enriched river water) will be implemented to create optimal growing conditions. Step-by-step, the water level will be increased to stimulate as fast as possible marshland accretion, while maintaining yearly flooding cycles, until present water levels are reached. The slowly increasing water level will reduce the mineralization of newly formed organic soil and therefore maximize the increase of soil thickness. The pilot will research the validity of the hypothesis and will aim to find the optimal mix of water discharge, sediment availability and flooding cycle to attain fastest accretion rates. In principle a drowned 'polder' will be most suitable, where as little as possible new construction is needed to provide suitable control over the hydraulics.

- **Accelerated natural salt or brackish water marshland development pilot**. This pilot project is quite like the previous pilot project, but now for a salt or brackish environment instead of a fresh water system. For this pilot daily water level variations should be allowed according to local tides.

- **Accelerated saltwater marshes development pilot**. A pilot is proposed to study the applicability in the Louisiana coastal area of the traditional Dutch method of saltmarsh creation, which has been applied in that country for hundreds of years, with the aim of land-reclamation and shore stabilization. This method is based on the reduction of local sediment losses to longshore sediment transports. This is realized by reducing currents parallel to the shoreline. At the same time, shoreward transport of sediment due to waves and currents is maintained. In the Dutch situation, Spartina was planted to fix the freshly deposited sediments. The pilot project will test the validity of the method and optimize the spatial design, including for example the question whether or not straight sections as applied in the Dutch design are appropriate. In the pilot project this method could be combined with the deposition in the study site of dredged fine sediments.

- **Pilot to increase the effect of fresh water discharge** to optimize marshland growth and increase the mixing zone with saline waters. This experiment aims to maximize the effect of water discharges into marshland areas that are already opened up by canals. Areas will be semi enclosed by low eco-levees (ridge levees) to enhance the flooding effect and residence time of the discharged fresh water. Plugging of canals will be considered to further enhance the effect of freshwater discharge. In order to reduce steep gradients between fresh and saline water, the semi-enclosed area will provide an

optimized mixing zone that allows free exchange of water and biota in and out of the semi-enclosed area.

- **Lake segmentation pilot.** Opened-up lakes in eroded marshland area are marked by stronger currents and more waves that erode marsh edges. In this pilot project, artificial low eco-levees (ridge levees), islands and suitably placed oyster reefs will be utilized to divide lakes into segments. This will reduce energy levels but maintain required flow. If land-subsidence rates are close enough to background levels and sediment availability is sufficient, marsh growth from existing and new marsh edges should tend to reduce remaining lake area in a land formation process. This process could be enhanced by additional sediment supply.

- **Sediment diversion pilot**. Existing river diversions (Carnarvon, Davis Pond) divert river water from the upper layer of the river. It is recognized that during low river flows the sediment concentration in the river does not differ substantially over the vertical, but during high flows sediment concentrations near the river bottom can be substantially higher than along the water surface. This pilot is aimed at developing a structure that diverts water from the bottom layer of the river, thereby diverting water with higher sediment concentrations. As an experiment, a relatively small scale diversion structure (a pipe) could be added to an existing diversion structure. Continuously measuring sediment concentrations in the water diverted from the river surface and from the bottom layer will provide useful information on options to increase sediment diversion.

Communication with stakeholders

Flood management measures can be complementary to environmental interests. This is the case when measures involve the restoration or creation of marshlands that protect or encourage the re-establishment of certain kinds of habitat. In general, however, environmental interests favor less engineering and lower rather than higher levees. Also, dredging operations are generally controversial. This may put environmental groups in strong conflict with those advocating improved flood protection. The challenge in communication with stakeholders about the project is to avoid misinterpretations about (1) the future ecosystem without interventions, and (2) what exactly certain measures entail. Avoiding such misinterpretations is essential in a broad acceptance of the unavoidable loss of environmental values at the short term, in favor of future environmental gains. Communication with stakeholders is essential for decision making to be informed and constructive.

8 Work plan for the remainder of the project

This chapter provides a work plan for the second phase of the project.

During a presentation of interim results to USACE in New Orleans on 14 March 2007, the project team presented first ideas about possible measures alternative strategies to reduce flooding risks and stabilize the delta. These strategies are composed of three main alternatives (‘open’, ‘semi-closed’ and ‘closed’ estuaries), with three variants for the ‘open’ alternative. Hence, in total, five alternative strategies were presented.

USACE expressed the desire that the project team would further detail these five alternatives in the remainder of the project, and the following work plan details the activities involved.

Work plan

The work plan for the remainder of the project is composed of the following elements:

1. Carry out the following hydraulic and morphological analysis:
   a) develop a model to calculate the surge reduction on Lake Pontchartrain in case of a semi-open flood defense. This implies a levee between Lake Borgne and Lake Pontchartrain, but with openings that have roughly the same wet cross section as the Chef Menteur and Rigolets passes. This calculation will be carried out for the Katrina event, but wind speeds increased to Category 5. The result will be used to reach conclusions about the feasibility of the semi-open system, and to determine to increase in protection level of New Orleans if this measure were to be implemented.
   b) Use the result of this calculation to estimate the size of openings in levees in the Barataria basin, also for the alternative with semi-open defenses.
   c) Tune the hydraulic and morphology model developed for averaged conditions, in particular for parameters used to describe the sedimentation process. This work includes a literature search on sedimentation parameters, and a sensitivity analysis on these parameters. Apply the resulting model to estimate the sedimentation processes in case of a short-cut in the Mississippi Birdfoot.
   d) For the case of a short-cut in the Birdfoot, apply the Delft3D hurricane model to determine the effect on river stages during a hurricane event, in order to answer the question whether or not a barrier would be required in the Mississippi River. The concern is that with a shorter river between New Orleans and the Gulf, hurricane surges may lead to unacceptable surge levels on the river close to New Orleans. To analyze this, an upscaled Katrina event will be used with a hurricane track that essentially follows the river.
   e) For the case of a short-cut in the Birdfoot, apply the Delft3D model to calculate the fresh water distribution in the delta under normal low flow conditions, not only influenced by tides (this calculation is already report in Appendix D), but also under the influence of wind. The concern here is that salinity levels in the Barataria salt water marshes may become too high.

2. Estimate the required height of levees in the five alternatives. The project team proposes to derive a first order estimate of these heights by using the stage-frequency curves that resulted from the IPET-project for some 150+ locations along the coastline of Louisiana. It is noted that applying these curves does not take into account the effect of the presence of these levees on surge heights just outside these levees. This effect may be significant, but the project team suggests that ignoring this effect is acceptable for a study at reconnaissance level.

3. Derive cost estimates based on unit prices for all measures that are part of the five alternative strategies.

4. Continue the work on the risk based approach as described in Appendix E of this report, and apply updated figures on flood damages (the project team already received additional information on this point from USACE), updated figures on flooding probabilities in the existing situation (to be received from USACE / IPET Volume VIII), and the cost of measures to be derived in this project. Determine the benefit/cost ratio for the five alternatives.

5. Estimate the flooding frequency reduction and hence flood risk reduction in the various polders for the five alternative strategies.

6. Carry out an impact assessment for the five alternatives, applying the criteria specified in Appendix A of this report. It is noted, that the score on many of these criteria will be based on expert judgment.

7. Report writing (aimed at an executive summary of several pages, a main report of about 30 pages, and appendices of in total about 200 pages). This work includes:
   a) reporting on research results, conclusions and recommendations;
   b) completing the various appendices of the report, including reworking and updating text, improving figures and tables, list of references, etc.;
   c) drafting figures that identify measures in each alternative strategy;
   d) drafting of an executive summary;
   e) editing of the report by a native speaker.

8. Presentation and discussion of project results to USACE on 19 June, 2007 (Delft); the so called 90%-meeting.

9. Submission of the Second Interim Report (to be considered as the Draft Final Report) at in the second half of June (so within 3 months after the start of the project).

10. Processing comments on the Second Interim Report and submission of the Final Report.

Reduction of the originally proposed effort for specific topics

Detailing five alternatives deviates from the project contract, which asks for research on one strategy, namely a strategy in which the development of levees (either traditional levees or eco-levees) is combined with dredging a short-cut in the Birdfoot, thereby essentially ‘giving up the Birdfoot’.

To balance the additional effort required to detail five alternatives, the project team proposes to reduce the effort on the following items:

1. Overall, the depth of the analysis for five alternatives will be less than originally proposed for one alternative. A wider scope leads to less detail as a consequence.

2. Port expansion. The original proposal presented the idea to investigate options for the development of new port facilities along the Mississippi River. New facilities close to the Gulf would reduce transportation costs since ocean going vessels would require less time for sailing long distances on the river at reduced speeds. The project team has second thoughts about this option, motivated as follows. If there was a real need for new port facilities, they would have been brought forward if not to say developed already. Also, if for example in this new port containers were to be loaded on trains for further transport, it is noted that train transportation is generally more expensive than ship transport. All in all, the team now suggests devoting less attention to this option when compared to the original proposal. Instead, options for port development will certainly be mentioned in the report, but research on cargo flows and demand for port facilities will not be undertaken.

3. Effects on navigation. The team proposes to limit the analysis on navigation to the nautical effects of giving up the Birdfoot (cross currents, etc.), and not attempt to quantify the effects on travel time and related economic effects.

4. Overall sediment balance of the Mississippi Delta. The project team recognizes the importance of this element of the project, but proposes to limit this analysis to the study of published material on this topic, and add to that expert judgement on the effects of strategies on the overall sediment balance.

5. An element in the original proposal was to attempt to determine the effects of measures in the Mississippi Delta on the hypoxia problem in the Gulf of Mexico, which is most probably caused by the nutrient load of the Mississippi River. The project team suggests limiting this analysis to expert judgment statement on these effects.

6. Finally, an element in the original proposal was to attempt to determine the effects of measures on fisheries in the delta. The project team suggests limiting this analysis to an expert judgment on these effects.

Information request

The project team requests USACE to provide the following information for use in the analysis:

1. Graphs that relate surge level to the probability of occurrence for a large number of locations in the planning area. These graphs were determined in the framework of the IPET-project for the entire area of coastal Louisiana. The graphs that apply to planning areas 1 and 2 are of course sufficient for the current project. These graphs will be published in IPET Volume VIII, but release of this volume has been postponed several times. The latest signal on the publication date is next July. That moment does not allow application in the current project, since by then the current project will be completed. Without these graphs, levee heights can only be estimated roughly, and hence cost estimates will be more uncertain. Also, the effects of measures on flooding probabilities will be more difficult to determine and hence will be less reliable.

2. Flooding probability in the existing situation (post-Katrina) for the various polders in the New Orleans metropolitan area and the Placquemines. Also this information is expected to be part of IPET Volume VIII. Without these numbers, the risk analysis will be less reliable, since the ‘starting point’ for this analysis (current flooding probabilities) will remain unknown.

3. Description of the current situation in the project area and the future situation without measures (LACPR). The original proposal assumed that a description of the existing situation and the future situation (year 2100) without measures would be made available to the project team. The advantage for the current project to make use of these descriptions is twofold: (1) the current project and LACPR would both use the same ‘starting points’ for the analysis, and (2) the work would not have to be carried out both by LACPR and the current project.

The project team requests USACE to make the three information items described in the above available to the project team ultimately 15 May 2007 for use in the current project.

If part or all of the above information is confidential and/or preliminary at this stage, the project team will treat that that information as such and refrain from citations and referencing to this information in upcoming reports.

APPENDICES WITH BACKGROUND INFORMATION

A Planning Framework and Criteria

This appendix is – in our view – close to completion..
Figures and tables will be improved.

A.1 Planning Framework

The systems analysis approach, applied in this project, has two main characteristics: (1) providing information that is relevant for decision makers (i.e. criteria) and (2) presenting a number of different alternative strategies which together cover the ‘playing field’ of possible solutions.

The systems analysis approach contains the project activities as outlined by Figure 14.

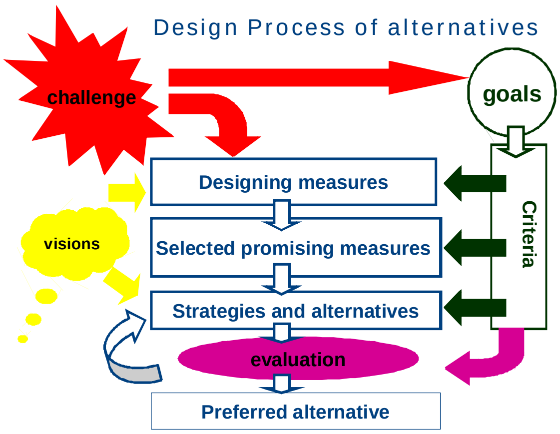


Figure 14 Schedule planning process

To provide the relevant information for a number of alternative strategies the subsequent activities in the systems analysis approach are repeated a few times (iteration). Each new cycle of activities provides a better focus on what the most relevant criteria are and what the possible solutions are.

Obviously, the trigger for the project is formed by the flooding disaster caused by hurricane Katrina. With this trigger in mind the objectives of the project have been defined and possible measures have been identified. The process of identifying possible measures and alternative strategies was enriched by the views of specialists in various disciplines and their views on the problem, its causes and possible solutions.

Next, the project objectives were detailed by specifying criteria, which have been used for the screening of measures. A quick scan of measures provided a comprehensive overview of discussion points and led to a relatively quick answer to the question whether or not a particular measure represents a realistic option or not. These discussion points proved important for the choices to be made in the planning process. The quick scan also led tot a differentiation between more promising and less promising measures.

After the selection of promising measures the design of strategies and alternatives started, keeping in mind the different visions on the type of solutions and the relevant criteria for decision making. These strategies and alternatives will be evaluated (*second phase of the project*), and pending the outcome of this evaluation may be redefined. The final result is the presentation of a number of alternative strategies, and a balance of pros and cons that can be presented to the decision makers. With that information a preferred alternative can be selected.

A.2 Objectives, criteria and performance indicators

Goal tree of main objectives and sub-goals

The overall objective of the project is to draft a plan for the long-term flood risk reduction and landscape stabilization of part of coastal Louisiana, which possibly also enhances the local and regional economy. Landscape stabilization is the strengthening of the natural functioning of the ecosystem, for example by the reintroduction of natural gradients, by improving the sediment balance and by increasing biodiversity.

The plan consists of a set of measures that lead to flood risk reduction and landscape stabilization, and which enable economic development. To measure the effects of possible interventions, criteria for evaluation follow are applied. Which criteria to use follows from the overall objective of the project. This overall objective of the project is worked out in five main objectives:

1. Increase in flood safety. This increase is expressed in the flood risk reduction for urban and for rural areas.
2. A more sustainable Delta, which in the case of the project means:
   a) improvement of the overall sediment balance;
   b) improvement in salinity gradients;
   c) improvements in ecosystem functioning; and
   d) improvements in the nutrients balance.
3. Retain and develop socio-economic values, i.e. navigation and other economic activities, historical values and social and cultural values.
4. High feasibility of measures, which in the case of the project means:
   a) The amount of time required for the implementation of measures. For some measures also time to maturation [3)] needs to be considered.
   b) High technical feasibility of the measures including maintenance and robustness.
   c) High flexibility in measures including adaptability and separability.
   d) High public support for measures.
5. Low costs, for investments and for maintenance.

[3]) *Time to maturation is defined as the time period between investments are made to implement a measure and the moment that benefits are realized; for example in case of river diversions to stimulate wetland development.*

These five main objectives and their sub goals are presented in a goal tree (see Figure 15). This goal tree provides insight in the five main objectives of the Dutch Perspective (the five items in enclosed in the blue frame) and gives an overview of sub goals that need to be met as much as possible. The green goals in Figure 15 are related to goals set by the LACPR (see text below).

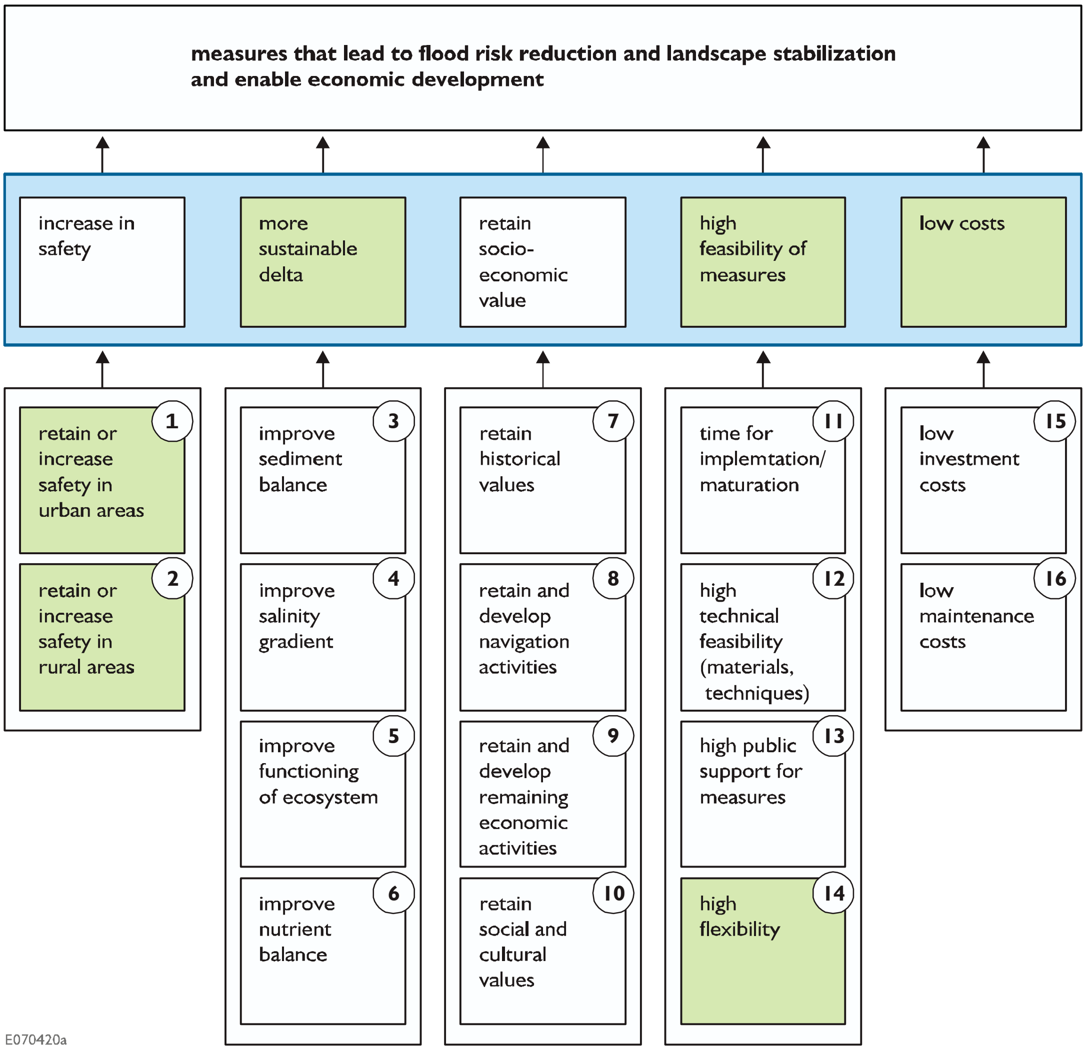


Figure 15 Goal tree

The balance of pros and cons for each alternative will be presented with these five main objectives. If necessary, also the relevant sub criteria will be mentioned. It is emphasized that these objectives will obtain different weights in the decision making of the alternatives. At this stage all objectives are assumed to have a similar weight. These criteria are used for the screening of measures and for the evaluation of the alternatives.

Criteria maintained by LACPR

LACPR has developed the following five initial criteria to evaluate the final alternatives for Coastal Louisiana:

1. **Cost effectiveness**: Cost versus amount of risk reduced or cost versus residual risk. Residual risk means damage and likelihood of damage, population at risk and likelihood of exposure.
2. **Robustness**: Plans or measures remain effective under various conditions.
3. **Adaptability**: Ability of measures and plans to be adjusted based on changes in future conditions (flexibility).
4. **Separability**: Ability to perform independently of other measures.
5. **Sustainability**: Ability to balance economic, ecological and social conditions to meet current and projected needs without compromising the ability of future generations to meet additional needs.

This list can be found in the Interim report on risk informed planning**.** No list of criteria is available at present to evaluate measures. However, the Project management Plan, Enclosure J of the Preliminary Technical Report of the LACPR, indicates the definition of evaluation criteria and performance measures in the proposed content of both the Preliminary and Final Technical Report. Unfortunately, in the actual text of the Preliminary report no criteria are stated (yet).

In the goal tree, the five USACE-criteria are incorporated in the goal tree (see the green boxes in Figure 15) as follow:

- **Cost effectiveness** is divided in two criteria; costs and safety.
- **Sustainability** can be found directly in the criterion More sustainable Delta.
- **Robustness, adaptability and separability** are incorporated in the criterion Feasibility of the project and Flexibility of the measures.

Criteria and indicators for performance

Since the main objectives are formulated on an abstract scale, it is not trivial to see whether or not goals are met by the proposed measures. Therefore 16 sub goals were added to the tree (numbers 1 thru 16 in Figure 15). From each sub goal a criterion is derived, which can be used to judge whether a goal is met or not. For each criterion we distinguished an indicator for the performance of the measure(s).

In the following tables, the five main objectives and their 16 sub goals are translated into a criterion and a performance indicator. Performance indicators have to be evaluated quantitatively when possible, or qualitatively otherwise. Within the Dutch Perspective most of the evaluation will be qualitatively.

In the next stage of the project these concept performance indicators will be defined in more detail including the evaluation method. Most likely, expert judgment will play an important role in deriving the scores for most of the criteria.

Increase in safety (Safety)		
Sub goal	***Criterion***	***Performance indicators***
1. Increased safety of the urban areas	Protection level urban areas Reduce in flood risk	Flooding probability (%) Reduce in flood risk
2. Increased safety of the rural areas	Protection level rural areas Reduce in flood risk	Flooding probability (%) Reduce in flood risk

More sustainable delta (Sustainable Delta)		
Sub goal	***Criterion***	***Performance indicators***
3. Improve sediment balance	Sediment balance	Area of wetland (ha) or sediment loss to deep water (t/yr) (less is better)
4. Improve salinity gradient	Salinity gradient	Presence of fresh water, brackish water and salt water marshes (expert judgment)
5. Improve functioning ecosystem	Ecosystem functioning	Qualitative assessment of ecosystem functioning (expert judgment)
6. Improve nutrient balance	Nutrient balance	Qualitative assessment of improvement of the nutrient balance (expert judgment)

Retain socio-economic value (Socio-economic value)		
Sub goal	***Criterion***	***Performance indicators***
7. Retain historical values	Presence of historical values	Number of historical values at risk (expert judgment)
8. Retain and develop navigation activities	Economic activities	Impact on navigation activities (qualitative)
9. Retain and develop remaining economic activities	Economic activities	Impacts on remaining economic activities (fisheries, tourism, agriculture and possibly new developments (qualitatively)
10. Retain social and cultural values	Presence of social and cultural values	Number of social and cultural values at risk (expert judgment)

High feasibility of measures (Feasibility)		
Sub goal	***Criterion***	***Performance indicators***
11. Time	Time for implementation and time to maturation	Number of years (expert judgment)
12. High technical feasibility	Technical feasibility	Qualitative assessment of maintenance robustness (+/-)
13. High public support	Expected public support	Qualitatively
14. High flexibility	Flexibility in implementation of the set of measures	Adaptability Robustness Separability

Low costs (Costs)		
Sub goal	***Criterion***	***Performance indicators***
15. Low investment costs	Investment costs	Costs ($)
16. Low maintenance costs	Maintenance costs	Costs ($)

Score in general:
++ meets goal completely
+ on the right track
+/- neutral
- moves away from goal
-- does not meet goal

During second phase of the project, new findings may lead to changes in the various criteria and performance indicators.

B Description of the physical delta system: geology

This appendix is – in our view - roughly 60 percent complete. The structure of this appendix is worked out, but the text still has to be elaborated.
Quality of figures will be improved and references will be checked.

B.1 Introduction

This chapter in fact is an excerpt of Roberts [4]1997 paper on the depositional framework of the Mississippi River delta. This paper stresses the cyclical evolution of the delta that is summarized in the *Delta Cycle Concept*. This concept is based on a large body of publications. The following abstract comes from this paper; it is an excellent summary.

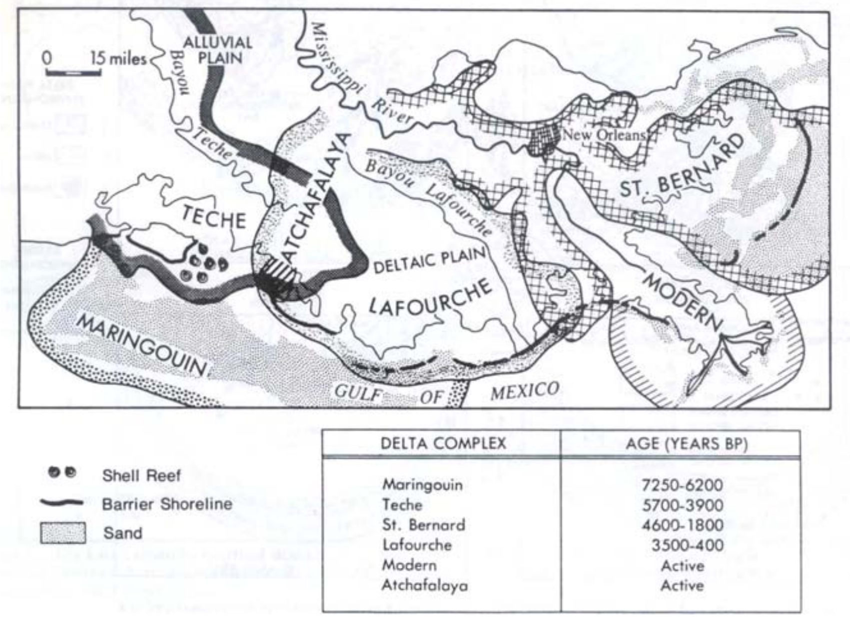
"Previous geologic research on Holocene Mississippi River deltaic deposits has verified that the present delta plain and associated nearshore barrier islands and submarine shoals are either direct or indirect products of cyclic delta-building events that have operated on a variety of temporal and spatial scales. A major depositional element of the modern delta plain is the <u>delta complex</u>, of which there are six: (1) Maringouin, (2) Teche, (3) St. Bernard, (4) Lafourche, (5) Balize, and (6) Atchafalaya. Major delta-building events have occurred at a frequency of one every 1-2 thousand year. Deposits associated with the six major delta complexes are fundamental constructional units of the delta plain, which collectively covers an area of ~ 30,000 km^2. Sedimentary deposits associated with these delta-building events range in thickness from 10 to 100 m. Their construction is modulated by stream capture, which develops a new delta complex by way of a new river course. Delta complexes may be comprised of one or more <u>delta lobes</u>. As a product of this delta switching, the depositional architecture of a delta plain consists of laterally offset and stacked delta lobes. Within delta lobes are <u>subdeltas</u> and even smaller <u>crevasse-splays</u>. These smaller-scale deltas sedimentologically and geomorphically mimic their larger delta lobe counterparts, but they are considerably thinner, cover less area, and have a shorter period of development and abandonment. Subdeltas are usually < 10 m thick and may fill shallow bays that cover over 300 km^2. They build and deteriorate on time-scales of 150-200 years. Crevasse-splays or overbank splays are < 5 m thick, cover only a few square kilometers, and are abandoned after several decades of active growth.

Each delta evolves through a rapid regressional phase as water and sediment are captured from an antecedent river course. If highstand conditions persist long enough, deltas may prograde to the outer shelf to form wedges of deltaic sediment much thicker than their inner shelf counterparts. The delta-building process starts with the filling of interior lakes (lacustrine deltas), which is followed by bayhead delta-building at the coast, and finally by progradation across the marine shelf (shelf delta).

---

[4] *Roberts, HH, 1997. Dynamic changes of the Holocene Mississippi River delta plain: the Delta Cycle. Journal of Coastal Research, 13 (3): 605-627.*

Delta complexes and delta lobes, as well as their smaller counterparts, experience three phases of growth and abandonment: (1) rapid growth with increasing-to-stable discharge, (2) relative stability during initial stages of waning discharge, when sediment input balances the collective effects of subsidence, and (3) abandonment, followed by rapid subsidence-driven subaerial delta deterioration. In the rapid growth stage, formerly eroding-subsiding coastal environments experience delta plain accretion and coastal progradation from renewed sediment input. On the abandonment side of the cycle, marine processes overwhelm fluvial processes and rework the delta perimeter. Forced by the combined processes of subsidence, the delta surface undergoes progressive submergence. Transgressive sand bodies created by wave reworking of the delta evolve from headland beaches and spits, to barrier islands, and finally to submarine shoals as the abandonment phase is completed."



DELTA COMPLEX	AGE (YEARS BP)
Maringouin	7250-6200
Teche	5700-3900
St. Bernard	4600-1800
Lafourche	3500-400
Modern	Active
Atchafalaya	Active

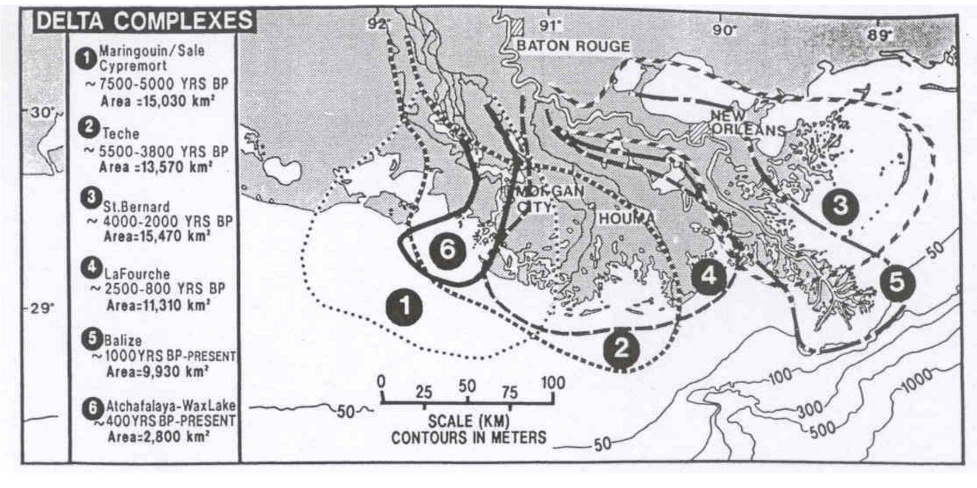


Figure 16 Two illustrations, showing different aspects of the delta lobes of the Mississippi Delta. Note that the ages of the lobes can vary from publication to publication

Characteristics of the Mississippi River delta:

- All Holocene deposits have been laid down by a meandering river; this implies that the river discharge did not fluctuate significantly during this period.
- The mean river discharge is 15,400 m^3/s, the peak discharge is almost 60,000 m^3/s.
- Then yearly sediment load is 621 million ton (*other sources indicate currently about 200 million ton/yr*).
- Bed load: 90% fine sand; suspended load: 65% clay, 35% silt (figures for lower reach of river; from Coleman, 1988 [5]).
- Atchafalaya River receives 30% of discharge Mississippi River (diversion near Old River, North of Baton Rouge); Red River joins Atchafalaya River downstream of this point, total discharge of 6,500 m^3/s.
- Sediment discharge of Atchafalaya onto shelf: 220,000 ton/yr (Roberts et al., 1980[6]).
- Delta builds out into relatively quiet basin: mild wave- and tidal conditions, delta geometry river dominated.

B.2 Delta Cycle

Cyclic delta building:

1. rapid progradation;
2. river switching;
3. transgressive reworking of deposits;
4. at the same time building of new delta lobe at new position: 'delta switching'

Several time- and spatial scales of delta building ('deltas within deltas'), from large-scale to small-scale:

1. Holocene *delta plain*
2. *delta complexes*; Marinqouin, Teche, St. Bernard, Lafourche, Balize, Atchafalaya (see Figure 16)
3. *delta lobes*, related to main distributaries river
4. *subdelta*, related to 2nd order distributaries
5. *crevasse splay* / *overbank splay*

delta complex:

- time scale: 1,000-2,000 years
- surface area: 15,000 km^2 marshland
- sediment sequence (on inner shelf) c. 30 m thick

subdelta:

- filling in shallow embayments between main distributaries
- thickness ~ 10 m (5-20 m)
- max. surface area c. 300 km^2
- period of cycle (building - abandonment - subsidence) 150 - 200 years

[5] *Coleman, JM, 1988. Dynamic changes and processes in the Mississippi River delta. Geological Society of America Bulletin, 100: 999-1015.*
[6] *Roberts, HH, RD Adams & RHW Cunningham, 1980. Evolution of sand-dominant subaerial phase, Atchafalaya Delta, Louisiana. American Association of Petroleum Geologists Bulletin, 64: 264-279.*

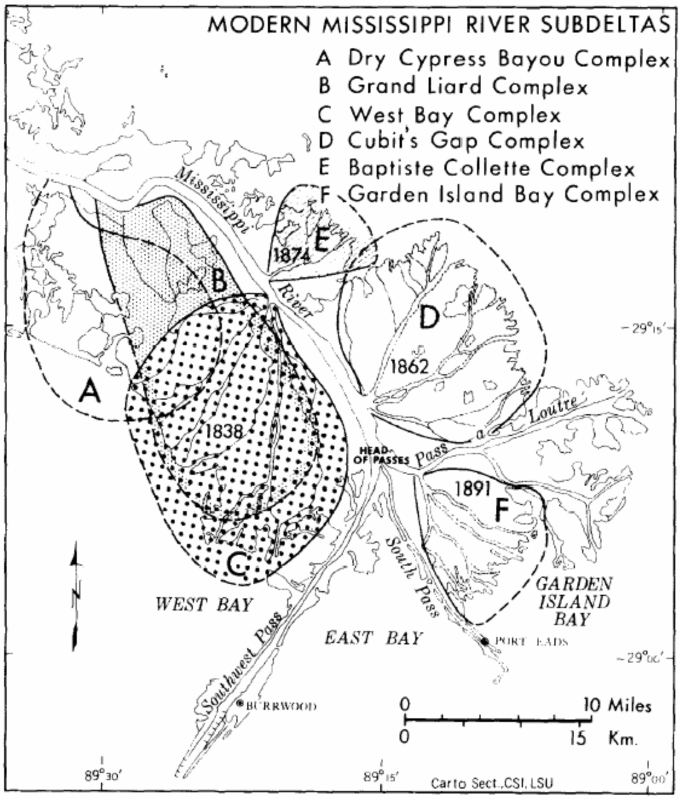


Figure 17 Index map showing subdeltas of the modem Mississippi River Delta in South-eastern Louisiana. Dates indicate the year of crevasse opening. Dry Cyprus Bayou and Grand Liard subdeltas were active prior to the 1800s and have not been included in this study (from Wells & Coleman, 1987[7].

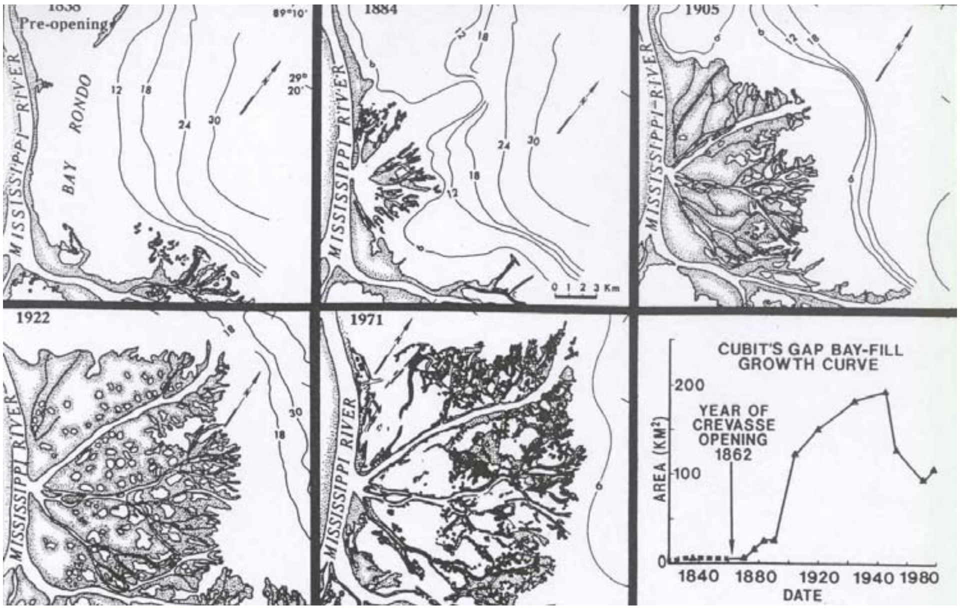


Figure 18 The development of Cubit's Gap, a typical subdelta that is part of the Birdfoot (from Wells et al., 1983[8])

[7] Wells, JT, & JM Coleman, 1987. Wetland loss and the subdelta life cycle. Estuarine, Coastal and Shelf Science, 25 (1): 111-125.

evolution of interdistributary bay deltas (subdeltas):

- suspended sediments, leaking through small breaks channel banks / levees
- coarser sediments after widening/deepening breaks
- rapid progradation leads to deterioration of channel efficiency; consequence: sediment supply < subsidence (compaction + dewatering): marshland disappears from proximal end - open water between subdelta levees - infilling with new overbank splay

crevasse splay:

- period deposition – erosion: decades
- thickness: meters
- surface area: some km^2

The Delta Cycle (see Figure 19) comprises two evolutionary modes:

1. *Delta initiation and rapid growth*: fluvially dominated regressive phase:
   a) stream capture
   b) establishment channel network

2. *Delta abandonment and deterioration*: marine-dominated transgresssive phase
   a) abandonment of channel network
   b) subsidence of lobes
   c) transgressive reworking of lobes: formation of sandy deposits by reworking of sediment: beaches > spits > barrier islands > submarine shoals

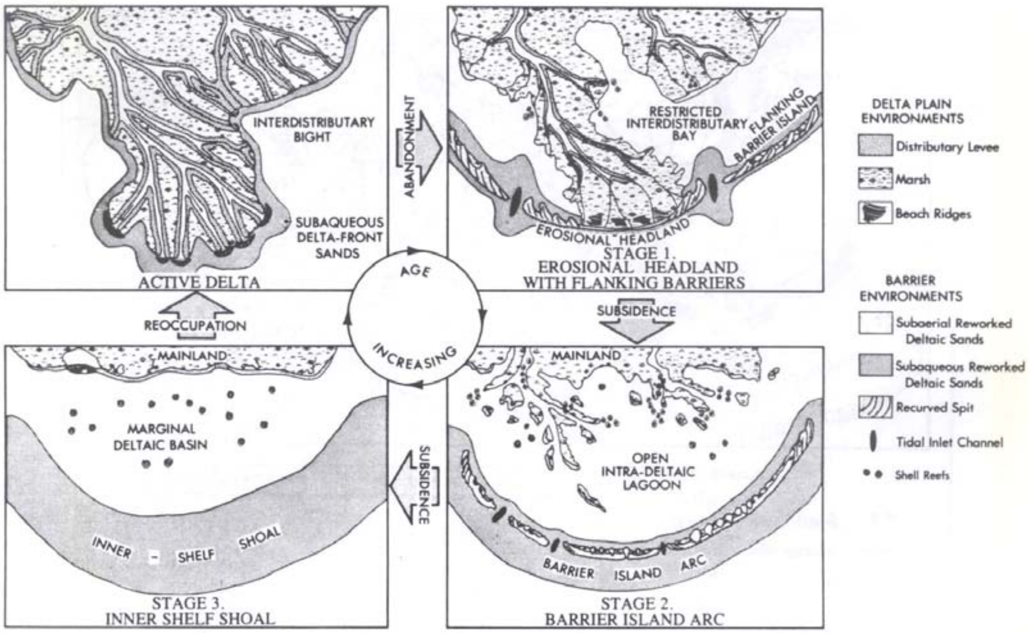


Figure 19 Conceptual model describing the Delta Cycle.

[8] *Wells, JT, SJ Chinburg & JM Coleman, 1983. Development of Atchafalaya River Deltas: Generic Analysis. Report to U.S. Army Corps of Engineers, Waterways Experiment Station, Contract DACW 39-80-C-0082, 98p.*

Delta Cycle, Phase 1; Delta building

See Figure 19, panel 'Active Delta'.

- stream capture
- sediment available
- delta building:
  step 1; infilling of inland lakes and alluvial plain
  step 2: building of delta(s) at the coast: bayhead delta(s)
  step 3: building out on the shelf
  examples: steps 1 + 2 Atchafalaya; step 3 Balize

Case: Atchafalaya:

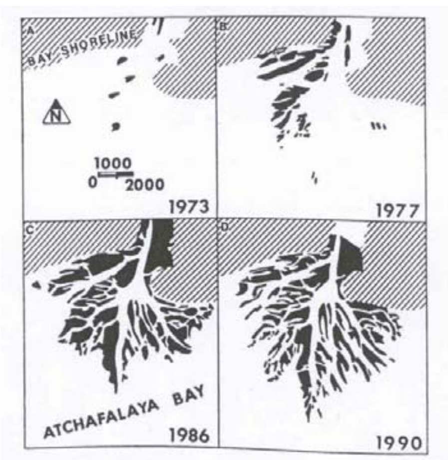
- stream capture in 16th century
- infilling of inland lakes (lacustrine delta filling of shallow lakes)
- increase in efficiency early to mid 19th century
- stabilization of discharge in 1963 by control structure (30% discharge Mississippi River)
- first sedimentation at coast since 1950 (bayhead deltas), after infilling of inland lakes

Lacustrine delta:

- sediment sequence coarsening upwards in grain size: laminated, bioturbated lacustrine clays (prodelta) > silty clays > silts (delta front) > sand (distributary mouth bars, subaqueous levees)
- subsidence causes backswamps to develop on top of this sequence: highly bioturbated, fine-grained deposits, rich in organics

Bayhead delta:

- formed after big flood in 1973: scouring of lower reach of Atchafalaya River, releasing medium- to fine-grained sand, flushed out to sea
- unusually high discharges in 1974 and 1975 caused rapid expansion of delta
- Note: volume of sediment deposited in bayhead delta is larger than input in Atchafalaya River at Old River: erosion of river bed
- marshlands along edge of Atchafalaya delta benefit from large supply of suspended sediment; strong accretion and increased productivity of vegetation since late 1960s
- coastal accretion downstream of bayhead deltas (in Chenier Plain to the West)



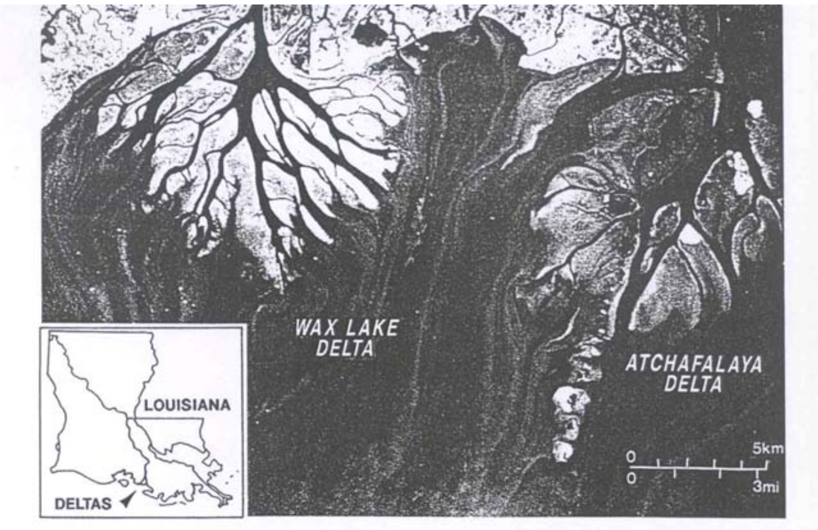


Figure 20 Illustration of the growth of the bayhead deltas of the Atchafalaya River.

Shelf-stage delta:

- Balize / Birdfoot
- Progradation over last 1,000 years
- Bounded by lobes of St. Bernard and Lafourche, causing the Birdfoot to prograde into deep water
- deep water: slow progradation, thick sediment sequence (from ~30 up to > 100 m)
- since 1850 c. 50% reduction in sediment load in lower reach Mississippi River (changes in land use; dam construction; increase in discharge Atchafalaya River)
- elongate sand bodies formed by progradation of distributary mouth bars ('bar finger sands'), causing updoming of sea bed consisting of prodelta mud ('mudlumps') by loading
- progradation of Southwest Pass: 12-13 km/cent.: delta front progradation 125 m/yr, sediment accumulation ~ 1 m/yr

Note: architecture of Birdfoot differs from that of other delta complexes: inner shelf deltas:

1. Thin inner shelf deltas
   a) prograde very rapidly
   b) develop many elongate and branched distributaries
   c) have thin widespread distributary mouth bar sands that may merge into 'delta-front sand sheets'
   d) accumulate a vertical sedimentary sequence that is usually less than 20-30 m thick (channels often cut completely through sediment sequence)
2. Middle to outer shelf (Balize) delta
   a) built into relatively deep water
   b) constructed rather isolated elongate distributary mouth bar sands that thicken abnormally at the expense of underlying prodelta clays
   c) developed a thick prodelta clay base over which coarser facies are prograding
   d) experienced slope instabilities at the delta front, caused down-slope transport
   e) accumulated a vertical sequence over 100 m thick

Delta Cycle, Phase 2; Delta abandonment and deterioration

See Figure 19, panels illustrating stages 1 – 3.

Delta lobe evolution:

- branching distributaries continues > network efficiency (water & sediment) decreases
- continuous progradation: reduction in gradient promotes stream capture upstream: *shift from active accretion and progradation to subsidence-driven processes and marine reworking !*

In present-day delta different stages of deterioration and marine reworking can be distinguished, see Figure 21.

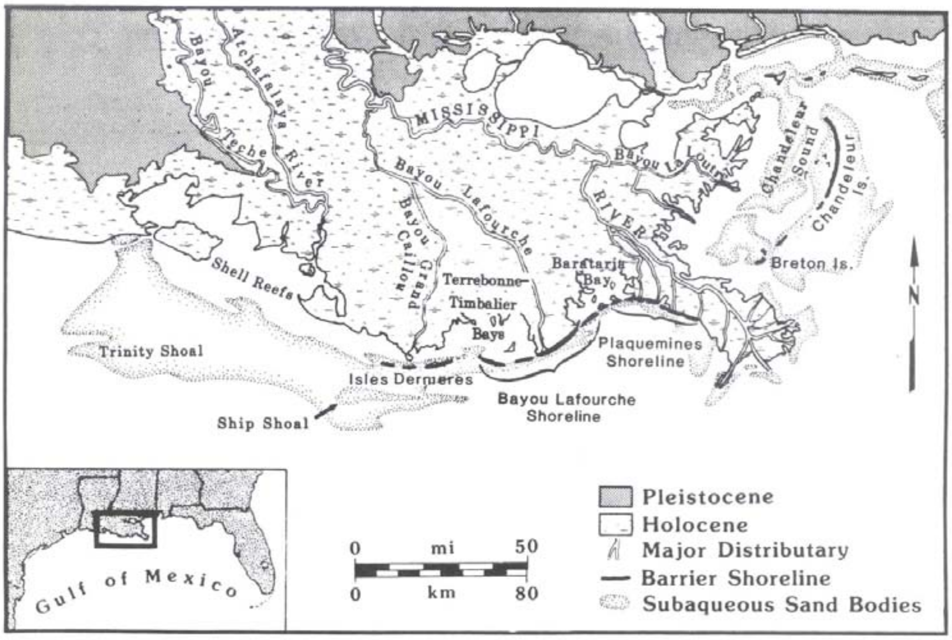


Figure 21 Morphology of the Mississippi River delta. The different shorelines represent different stages of deterioration of inactive delta lobes.

Important effects of subsidence:

- loading of distributary mouth bar sands on prodelta clays ('mudlumps')
- postdepositional dewatering and compaction of lobe sediments:
  most important components of Relative Sea-Level Rise (RSLR),
  consequences: land loss, marine transgression in delta plain; thickness of Holocene deposits is important: the rate of subsidence increases with the thickness of the deposits

So one would expect delta lobe situated in a valley (thick sequence) to experience more subsidence and faster marine transgression, e.g. Lafourche as opposed to St. Bernard, the latter being emplaced on a shallow Pleistocene surface

Note: Does that show in the phase of transgression? Not obvious!

<u>!! Expectation: Birdfoot will subside rapidly after significant decrease in sediment supply, caused by its thick sequence of Holocene deposits</u>

Note: What does that mean for redistribution of these sediments? Also taking into account the long distance to the delta plain

At delta lobe scale, subsidence under load, large-scale basinal down-warping and eustatic SLR will contribute to marine transgression

<u>sediment reworking during regressive phase</u>

local reworking of active delta lobes also takes place during progradation, e.g. in bays along channels: abandonment > subsidence > marine transgression
consequences:

- channel mouths reworked into thin beaches (<1.5 m thick),
- oyster reefs are growing on drowned levees

<u>deltaic headland retreat - beach, spit and barrier development (Fig. 4, Stage 1)</u>

- subsidence and reworking by waves:
- erosion of headlands > formation of thin beaches, washover fans
- sand transported laterally, forms barrier islands and recurved spits
- coastal retreat *Caminada-Moreau headland*: > 3 km between 1887 and 1988 (~ 33 m/yr), Note: this headland still receives sediment from Bayou Lafourche and its distributaries !

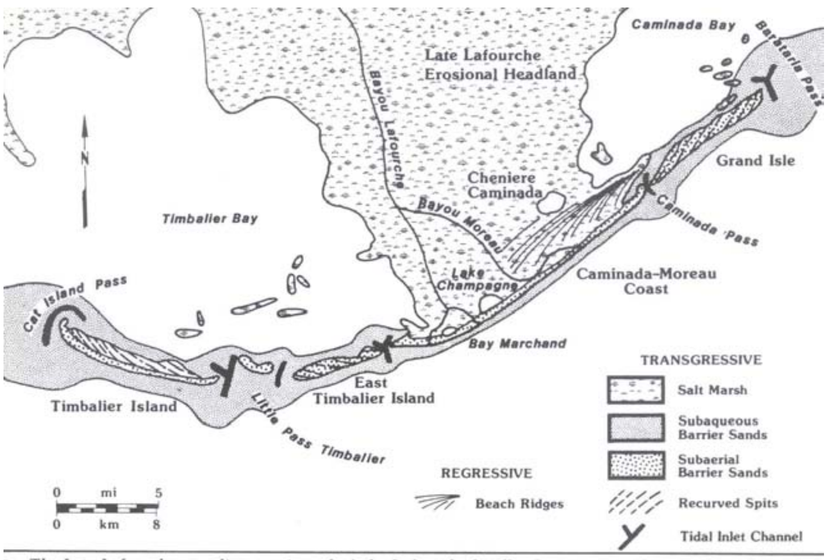


Figure 22 Detailed view of the erosion of the Caminada-Moreau headland. Erosion of the headland causes winnowing of sand from the deposits. This sand is redistributed into barriers, barrier islands and spits. See description in text below.

1. rapid coastal retreat, together with growth of bays caused by subsidence, leads to separation of barriers from delta plain, causing them to became *barrier islands*
2. barrier islands retreat landward by overwashing and grow sideways by wave-driven longshore transport

3. tidal prisms increase with further subsidence of interdistributary bays, leading to storage of increasing volumes of barrier sand in ebb- and flood-tidal deltas; coast changes from wave-dominated into tide-dominated (*still mixed energy in my opinion*); barrier sands are comparatively thin (< 6 m)

barrier island arc formation (See Figure 19, Stage 2)

1. coastline marsh retreats faster than barrier islands
   former caused by subsidence, lack of sediment input and saltwater intrusion
   latter caused by subsidence and wave action
2. barrier islands left behind in open water, develop into island arc

Example: Chandeleur Islands (St. Bernard lobe)

See Figure 21 for location.

- c. 75 km long, dunes in Northern part, c. 100-200 m wide
- retreat over period 1885-1969: 9.1 m/yr in South and 7.2 m/yr in North; period 1855-1989: 1.5 m/yr in South to 18 m/yr in North; land loss over this period 7.6 ha/yr
- breaching and overwashing during storms

submarine shoal formation (See Figure 19, Stage 3)

Sediment supply stopped, subsidence continues: barriers submerge, change into submarine shoal.
marshes to landward disappeared by then; only bay remains

Example: Ship Shoal

See Figure 21 for location.

- 50 km long, 5-12 km wide, 4-6 m thick (~ 1.25 billion m^3 of sand)
- Landward slope steeper than seaward slope; indicates landward migration, 7-15 m/yr

****
Remarkable and relevant statements (highlighted with *italic*):

Wells, JT, 1996. Subsidence, sea-level rise, and wetland loss in the lower Mississippi River delta. In: JD Milliman and BU Haq (Eds.), Sea-Level Rise and Coastal Subsidence, Causes, Consequences and Strategies, p. 281-311. Kluwer.

> ABSTRACT: Since late Cretaceous, depocenters with oscillating deltas and migrating shorelines have provided a fundamental geologic rhythm to the coast of Louisiana. Sites of deltaic sedimentation have shifted, sea level has risen and fallen by more than 100 m, and sequences of preserved deltas have been vertically stacked in the geologic record. This paper summarizes, in the form of a case history, recent changes in the modern Mississippi Delta with special emphasis on the causes for geometrically increasing rates of wetland loss that have been experienced since the turn of the century. *Rates of relative sea-level rise and discharge of freshwater down the main stem of the Mississippi River (North of Louisiana) appear to have been constant throughout the 1900s, indicating that the demise of the Mississippi Delta is probably a result of an*

inadequate sediment supply and an inefficient sediment delivery network. The combined effects of levees that prevent overbank flooding and funnel sediments to deep water, upstream dams that trap sediments in the Missouri and Arkansas River basins, and formation of a new delta lobe 150 km to the West have had a profound effect on sediment supply. This loss of sediment load is occurring as the Mississippi Delta is nearing the end of its natural 1000-yr life cycle, and has overwhelmed the ability of fragile wetlands, already in a state of delicate balance, to survive the combined effects of global sea-level rise and subsidence. *Mitigation through creation of an extensive network of artificial diversions will slow the rate of delta deterioration but will **not** be able to rejuvenate a dying delta lobe.*

Snedden, GA, JE Cable, C Swarzenski & E Swenson, 2007. Sediment discharge into a subsiding Louisiana deltaic estuary through a Mississippi River diversion. Estuarine, Coastal and Shelf Science, 71: 181-193.

ABSTRACT: Wetlands of the Mississippi River deltaic plain in Southeast Louisiana have been hydrologically isolated from the Mississippi River by containment levees for nearly a century. The ensuing lack of fluvial inputs, combined with natural submergence processes, has contributed to high coastal land loss rates. Controlled river diversions have since been constructed to reconnect the marshes of the deltaic plain with the river. *This study examines the impact of a pulsed diversion management plan on sediment discharge into Breton Sound estuary, in which duplicate 185 $m^3 s^{-1}$ -diversions lasting two weeks each were conducted in the spring of 2002 and 2003.* Sediment delivery during each pulse was highly variable (11,300-43,800 metric tons), and was greatest during rising limbs of Mississippi River floods events. Overland flow, a necessary transport mechanism for river sediments to reach the subsiding back marsh regions, was induced only when diversion discharge exceeded 100 $m^3 s^{-1}$.
These results indicate that timing and magnitude of diversion events are both important factors governing marsh sediment deposition in the receiving basins of river diversions. Though the diversion serves as the primary source of river sediments to the estuary, *the inputs observed here were several orders of magnitude less than historical sediment discharge through crevasses and uncontrolled diversions in the region, and are insufficient to offset present rates of relative sea level rise.*

Wells, JT, & JM Coleman, 1987. Wetland loss and the subdelta life cycle. Estuarine, Coastal and Shelf Science, 25 (1): 111-125.

ABSTRACT: The rapid deterioration of marsh habitat observed during recent years in the modern Mississippi River Delta is a consequence, at least in part, of the natural life cycle of subdeltas. With life spans typically less than 200 years, *subdeltas or bay-fill deposits are scaled-down versions of major delta lobes, yet provide, through pulses of sediment, nearly all the subaerial land in an active delta.* Using maps, charts, and aerial photographs, curves were constructed for rates of change in land area, sediment volume, and linear progradation in the four subdeltas that have formed on the modern Mississippi River Delta since the first accurate survey in 1838. Results indicate that each subdelta (1) lasted for approximately 115-l75 years, (2) included both periods of growth and deterioration, (3) was initiated by a crevasse or break in the natural levee system, (4) showed linear advancement and volumetric growth during subaerial deterioration, and (5) displayed a new pulse of subaerial growth during the high discharge decade of the 1970s. *Contrary to popular accounts, demise of the Mississippi River Delta through deterioration of its subdeltas is not a result of the construction of artificial levees upstream or discharge of sediment off the continental shelf edge. Rather, it is attributable to a substantial decrease and fining of sediments being transported downstream to depositional sites within a delta that has developed, through natural processes, a complex and inefficient channel network for delivering these sediments.*

C Description of the physical delta system: wetlands

This appendix is- in our view - roughly 70 percent complete.
The current version contains (extensive) quotes from other publications. These will be reworked and condensed. We aim at less than 20 pages for this appendix, down from the current 28.
Figures and tables will be improved.
References will be checked and if necessary corrected

C.1 (Accelerated) subsidence rates

Subsidence rates for the Gulf Coast region estimated for Pleistocene and Holocene sediments provide a basis for comparing subsidence rates between geological and historical time scales. This comparison can be used to determine if historical subsidence rates are comparable to or greater than those expected from natural processes operating in the sedimentary basin. Paine (1993) used radiocarbon ages and elevations of Pleistocene strata and global sea-level data to estimate average geological (10^5 yr) subsidence rates of 0.02 to 0.05 mm/yr for the central Texas coastal plain. Similarly, Penland and others (1988), Roberts and others (1994), and Kulp (2000) all used radiocarbon ages and depths of peat deposits to estimate subsidence rates in the Mississippi delta for the past few thousand years. Analyses of Penland and others (1988) yielded subsidence rates that ranged from 1 to 5 mm/yr and averaged 2 mm/yr; those of Roberts and others (1994) yielded rates that ranged from 3 to 5 mm/yr and averaged 4 mm/yr. The most extensive database of radiocarbon dates for the Mississippi delta (Kulp 2000) yielded subsidence rates that ranged from 0.1 to 8 mm/yr and averaged about 1 mm/yr.

As expected, regional geological subsidence rates are higher in the Louisiana coastal plain because Holocene sediments are relatively thick compared to the Texas coastal plain where Holocene sediments are thin. From a theoretical viewpoint, subsidence rates of geologically young deposits should be high initially as pore water is expelled from the sediments and the sediments compact. Following the initial rapid compaction, subsidence rates should decline exponentially. This principle was illustrated for Holocene Mississippi delta sediments by Kulp (2000) who plotted calculated subsidence rates for the past 6,000 y. The plot showed that the trend of subsidence rates decayed exponentially with time to about 2 mm/yr after about 2,000 y.

Historical subsidence rates are calculated from elevation changes at benchmarks, which are periodically resurveyed by the National Geodetic Survey. Some re-leveling surveys in the Gulf Coast region are located along roads that cross the structural grain of the Texas coastal plain (Holzer and Bluntzer 1984; Paine 1993) and the Mississippi delta plain (Shinkle and Dokka 2004), and they also pass through or near producing fields (Figure 23 and Figure 24). Comparing data from first-order leveling surveys provides a basis for determining magnitudes and rates of subsidence for the intervening period.

Figure 23 Coastal Louisiana subsidence rates, centimeters per year (modified from Ramsey and Penland 1989; Penland and Ramsey 1990). http://biology.usgs.gov/s+t/SNT/noframe/gc138.htm

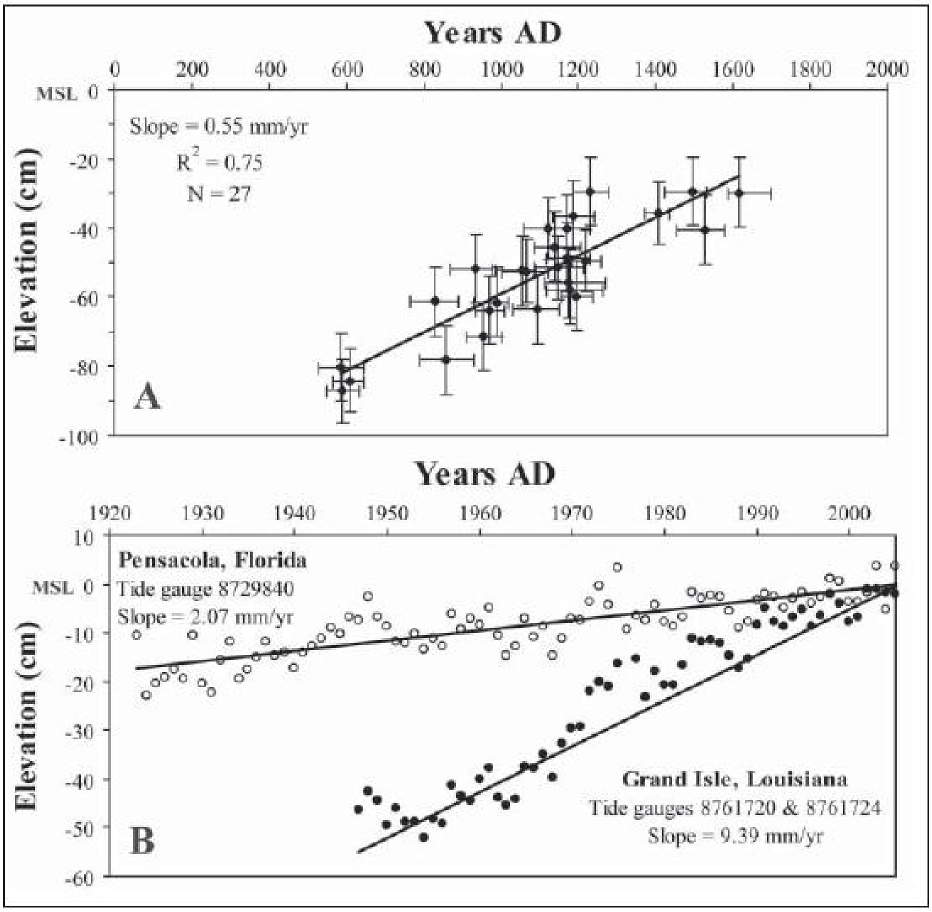


Figure 24 (A) Long-term trend of relative sea level rise for the period 600 to 1600 A.D. The data set contains 27 sea level index points and records approximately 55 cm of relative sea level rise. Data points (with age and elevation errors) are defined by the median of calibrated ^{14}C ages plus elevation of the center of basal peat samples dated. Two sub-samples were dated for each sample, and all but four index points were obtained by calculating a weighted mean of two 14C ages. Only one sample provided a stratigraphically reversed age and was rejected. MSL is present mean sea level. (B) Trend of relative sea level rise for two selected tidal gauges normalized to present mean sea level. Data were obtained from the U.S. National Oceanic and Atmospheric Administration's National Oceanic Service Center for Operational Oceanographic Products and Services. (ref: http://biology.usgs.gov/s+t/SNT/noframe/gc138.htm)

Analysis of leveling data from surveys in 1965, 1982, and 1993 along Louisiana Highway 1 between Raceland and Leeville (Figure 23) shows that (1) subsidence rates were substantially higher near producing fields and faults than between the fields, and (2) subsidence rates accelerated between the first and second periods of measurement. In this sub-region subsidence rates between 1965 and 1982 ranged from 1.6 to 12.0 mm/yr and averaged about 7.6 mm/yr, whereas between 1982 and 1993 they ranged from 8.2 to 18.9 mm/yr and averaged about 12.1 mm/yr.

Another way of detecting induced subsidence around producing fields is by comparing observed recent rates of subsidence with rates established for natural subsidence in the same region. For example, Morton and others (2001) estimated a minimum short-term subsidence rate for the Port Neches field in Texas during the period of maximum production. The estimated subsidence rate of 30 mm/yr is three orders of magnitude higher than the geological subsidence rates for the coastal plain estimated by Paine (1993). Accelerated rates of subsidence in South Louisiana can also be demonstrated by comparing geological and historical rates. The average historical subsidence rate in the Mississippi delta of 12 mm/yr (Shinkle and Dokka 2004) is roughly an order of magnitude higher than average geological rates of subsidence reported by Penland and others (1988) and Kulp (2000).

C.2 Ecosystem functioning and living resources

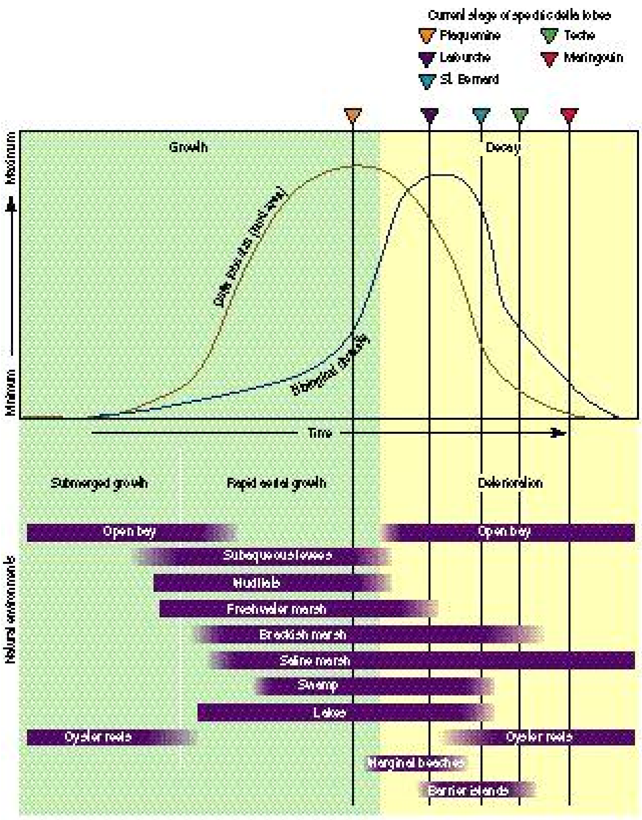
Cyclic processes

The cyclic geological development of the Louisiana coast leads to plant associations or communities that are determined by the stage of development or degradation of each delta lobe (Gagliano and Van Beek 1975; Figure 25). Following a period of rapid wetland formation during the progradational phase of a delta lobe, a longer period of lobe degradation follows the shift of the river to another location. Overlapping natural environments develop and decline as the lobe ages. The sequence begins with a shallow open bay into which the river begins to pour sediments. Infilling of the bay results first in subaerial mudflats, which later become freshwater marshes and swamps (Figure 28). The natural levees along the major distributaries are elevated by sediment deposition during the largest floods and form a skeletal network of high ground that becomes terrestrial habitat amid the wetlands and lakes.

As the delta lobe expands and the river's course is channelized, portions of the lobe that receive little direct freshwater input come under the influence of marine forces, and freshwater marshes slowly change to brackish and then to saline marshes. The river abandons the lobe slowly over many years, and the system becomes progressively more saline. The compaction of recently deposited sediments and the loss of a mineral sediment supply begin a period of net subsidence, during which time the land surface gradually sinks beneath the water, the plant cover dies, the substrate disperses, and the area reverts to a shallow bay. At the marine interface, reworking of the shoreline by waves, longshore currents, and storms forms beaches and headlands that become detached from the mainland when the interior marshes are lost. Thus, a barrier island system is one of the last expressions of a degrading delta lobe.

Neill and Deegan (1986) showed that habitat diversity increases with age of a delta lobe. Gagliano and Van Beek (1975) speculated that biological diversity also increases (Figure 25), with maximum diversity occurring during the middle of the destructional decay phase. As oceanic forces impose a strong salinity gradient, the landscape pattern increases in complexity, creating more and more habitat types (Figure 27). Of a total of about 16,000 square kilometers of wetlands in Louisiana, marshes occupy about 10,000 square kilometers and forested wetlands about 6,000; of this 6,000, about 600 are shrub-scrub (U.S. Geological Survey, National Wetlands Research Center data base, 1990).

The net result of a series of overlapping delta lobes is a row of estuaries from East to West along the coast, each bounded on the East and West by the natural levees of old distributaries and on the seaward edge by a barrier headland or island system. The interdistributary basin is flanked by the degrading lobes of earlier deltas, and the interior is a series of bays and freshwater lakes.



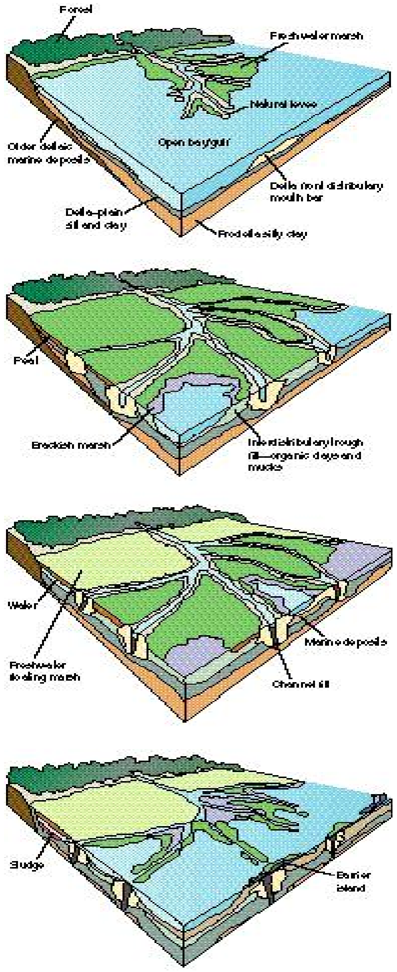


Figure 25 Graphical depiction of the growth and decay of a delta lobe (adapted from Gagliano and Van Beek 1975; Neill and Deegan 1986). Habitat and biological diversity peak in the early to middle stage of the decay phase. © Houston Geological Society

Figure 26 Sequence of growth and decline of a delta lobe

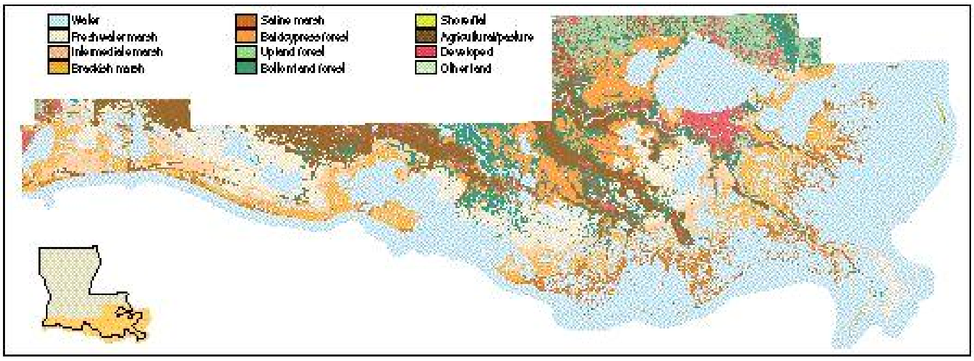


Figure 27 Map of major coastal habitats of Louisiana, 19881990 (data from U.S. Geological Survey, National Wetlands Research Center data base).

The water regime of each estuary is fairly isolated. The natural levees of the old major distributaries confine the small flows they now receive, so that the estuary has little direct freshwater input except from local runoff and rain. The elevated remnants of the natural levees of the minor distributary network fork out across the degrading delta lobe like the branching system of an old tree. When the remnants are young, they support oak forests, which are replaced by shrubs and finally, as they subside, by vascular marsh plants. The stark silhouettes of dead trees across a flat marsh is a common signal of the remnants of an old natural distributary.

Marshes lie between the branches of the distributary system, and as subsidence progresses they grow over and obliterate the lower ends of the distributaries with a thick skin of organic peat. The broad natural levees at the landward edge of the estuary are nearly all developed for human occupation. They were once terrestrial forests dominated by live oaks, but few patches of forest remain, as most are replaced by villages, sugarcane fields, shipyards, and seafood processing plants.

Landscape

The natural landscape of the Mississippi delta is characterized by a number of estuarine systems that are separated in space, but are connected form the land side by the flow of Mississippi water through its tributaries. Form the seas side, the tide moves back and forward along the coastline and provides Mississippi outflow water mixed with Gulf water to each estuary. Going from East to West at least four major estuarine systems can be identified, namely the Pontchartrain basin, Barataria and Terrebonne estuaries, Atchafalaya influence area and the Chenier plains. This structure is a result of the dynamic development of the major outflows of the Mississippi through time covering almost the complete width of the coastline of the state of Louisiana (700 km). Going from North to South, the flat land gently slopes toward the sea, producing a 100-200 km deep deltaic plain bordering the coastline. The landscape is dominated by ridge features, that have been deposited by tributaries or old outflows of the Mississippi river. Ridges are in general not higher than 6-9 m above sea level but are the highest points in the landscape and as such have been crucial as unique habitat and suitable location for agriculture and habitation. This landscape, where fresh and saline waters have been mixing, rich in nutrients and silt has been and is a great source of productivity that has been utilized by many species and has attracted man for thousands of years. The landscape has been, is and will be dynamic, meaning that erosive

and accreting processes will be counteracting each other with different results in different periods and locations. What is water can become land, what is land can become water and vice versa. Also there will be and have been transitions between fresh and saline environments as a consequence.

Biotopes from fresh to salt

Salinity gradients and inundation frequencies are dominant factors controlling the biotopes that are found in the estuarine systems. The most fresh biotopes are bottomland and ridge hardwood forests and freshwater swamp forests. Hardwood forests are dominated by ash, hackberry, oak and maple trees. They are an important nesting grounds for bald eagle and migratory songbirds. The swamp forests occur in areas that are more frequently flooded by fresh river water. Here the bald cypress and moss-draped tupelo are dominating trees.
Its waters are rich in crawfish. Nesting birds here are heron, ibis and egrets. If land is even lower, trees disappear and marsh biotopes dominate. Marshes are divided into four ‘zones’ going from fresh to salt, with subtle transitions in between. Fresh marshes are home the most diverse vegetation and fauna of the area. Vegetation is characterized by maiden cane, bulltongue and spikerush. Typical animals are frogs, ducks, alligators, turtles, muskrats, mink, otters, egrets, herons and hawks. Fresh marshes can form large floating surface on lakes, with thicknesses of many meters. Intermediate marshes, with some input of saline water have a changed vegetation and fauna, that can resist a little salt. This is the prime nursery habitat of brown shrimp, blue crab, gulf menhaden and other commercially and recreationally valuable species. More influence of salt results in the formation of brackish marshes, flooded with moderately salt water, here wire grass and salt grass start to dominate. This area is the area were high densities of blue crabs, shrimp, speckled trout and redfish are found. Dominating mammals are raccoons, mink and otters. The salt marsh, located most close to the sea is regularly flooded and is dominated by oyster grass. Here the same aquatic species are found, however sometimes in other stages of their lifecycle, while migrating between the estuary and the Gulf. The coastal edge is formed by a chain of barrier islands, consisting of fine sand, forming beaches backed by low dunes. Beaches and dunes are popular nesting and foraging areas for many birds such as gulls and pelicans. Migratory shorebirds and songbirds frequent these barrier islands. The sandy soil provides habitat for unique shrub vegetation, the submersed shallow sandy bottoms on leeward sides provide exceptional feeding grounds for many fish species. Behind the barrier islands, the bathymetry of is dominated by shallow water, dissected by a number of tidal passes and channels. These natural and man-made channels are the main conduits of salt water entering the estuarine systems.

The researchers working on the CLEAR modeling project proposed a concept to clarify the transition between biotopes based on changes in inundation and salinity. Figure 28 depicts the main idea.

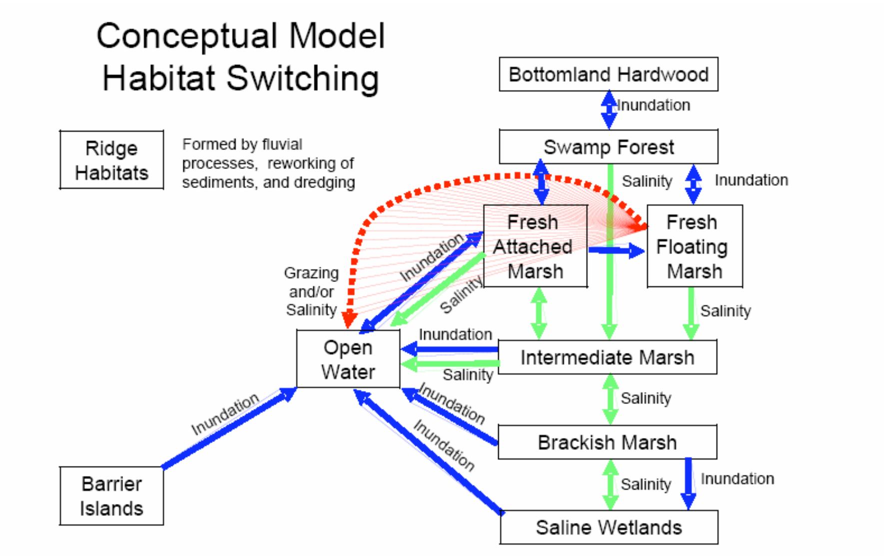


Figure 28 Concept of biotope switching processes in the Mississippi delta plain (Twilley et al, 2003). Note that grazing is also a factor leading to open water formation. (source: R.R. Twilley, 2003, Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) Model of Louisiana Coastal Area (LCA) Comprehensive Ecosystem Restoration Plan. Volume I : Tasks 1-8. Produced for DNR by Center for Ecology and Environmental Technology, University of Louisiana at Lafayette)

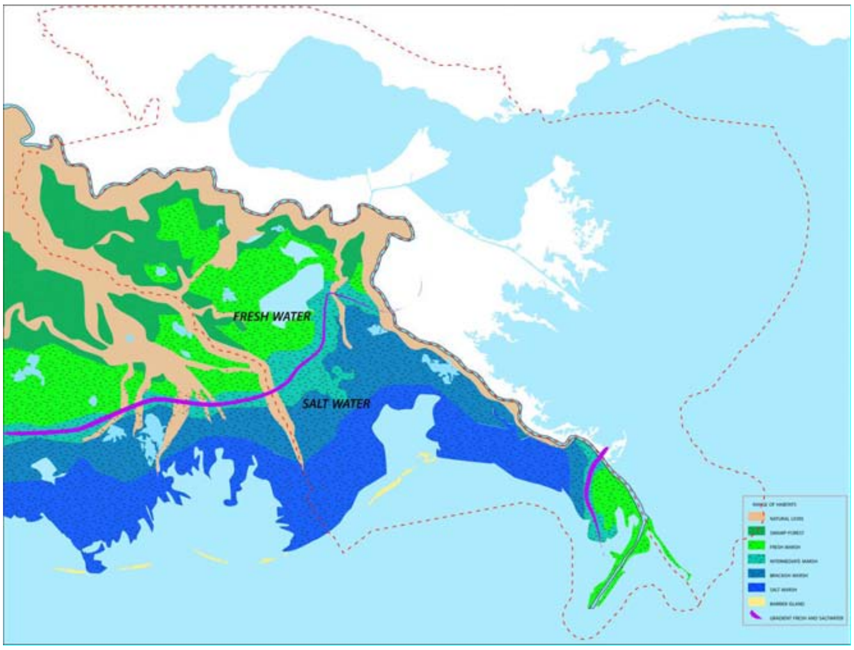


Figure 29 Biotope zoning in Barataria-estuary (source: BTNEP)

Key species

The North American Flyway passes directly over the Louisiana coast. More than 5 million migratory waterfowl spend the winter in the Louisiana marshes. Millions of neo-tropical birds utilize the area, while they cross the Gulf of Mexico.

Many animal species depend upon marsh and forest biotopes for their reproduction, nursery and food. Important biotopes have been reduced in area (for instance more than 200,000 acres of hardwood bottomland forest have been converted into agricultural lands after the 1950's. Much larger areas have been drained and converted before this period. This has reduced habitat area for the Louisiana black bear, making it a rare species. Special programs have been put in place more recently to protect the key species American bald eagle and the alligator. Populations seem to recover somewhat in the last decades. The massive and continuing marsh losses (about 50 km^2 each year, losses have been starting before the 1930's, about 600 km^2 from 2005 hurricanes Rita and Katrina alone) have reduced habitat area, but this is not yet clearly reflected in declines in fish and wildlife populations that depend on marsh habitat such as white and brown shrimp, blue crab or top-predators such as fish eating birds (osprey, bald eagle, pelican species). It is hypothesized that the availability of productive fresh marsh edges is compensating loss of marsh area, for the time being.

Fish and shellfish production

Important species are oysters, shrimps and crabs, bay anchovy, Atlantic croaker, red drum (redfish), spotted sea trout, largemouth bass and catfish. Oyster harvesting is a long term economically important activity. Oyster biomass seems to be stable. Oyster filtration capacity could be linked to water quality if densities are sufficiently high. Oyster habitat is optimal when salinities are not very high and not too low, fresh water input needs to be significant to make oyster grow in abundance.

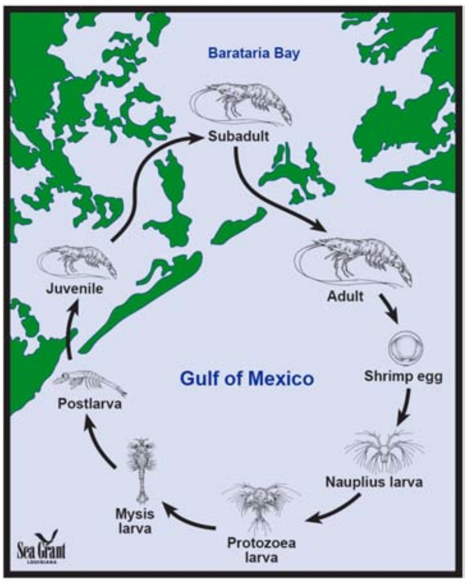


Figure 30 The life cycle of a shrimp, Elizabeth Coleman et al, 1999. Louisiana Sea Grant College Program, LSU, Baton Rouge, LA 70803.

Growth is dependent on salinity, temperature and sufficient phytoplankton production. Oyster habitat improvement is an important aspect of oyster management. The shrimp's lifecycle is linked to the estuarine systems (nursery) and the Gulf proper (reproduction). Its catch is the largest and most valuable fishery in Louisiana. Production seems to be stable but is influenced salinity, water temperature and tidal action. In total there are more than 200 species of finfish occurring in the estuarine systems. Anchovy and croaker are the two most abundant fish species and therefore an important part of the estuarine and coastal food chains. Red drum is an important recreational species, just like the largemouth bass. Catfish is sustaining both recreational and commercial fisheries. The latter two species are limited to the fresh parts of the water systems. Louisiana shrimp, crab and oyster production provide 26% of the total catch (by weight) in the lower 48 states of the USA. This fishery provides jobs for 40,000 citizens of the state. Total annual catch, including fish, is worth about 400 million dollar and ranks is as the second state considering fishery production.

Agriculture

Agriculture is dominated by sugarcane growing. In better drained places, soy bean, pecan, wheat and corn is grown. Many former soy bean fields have been converted to pasture lands after dramatic drops in price. It has been experienced in the area, that flooding with salt water of agricultural land, will make it unsuitable for cropping for up to ten years. Fertilizers used in agriculture are enriching waters in the estuarine systems. This has been resulting in blooms of (toxic) algae in lakes, that can affect survival and productivity of fish, crabs, shrimps and filter feeders such as oysters. Pesticides such as atrazine, that is used to combat weeds, are washed out into the groundwater, lakes and channels. This is causing elevated concentrations in drinking water close to or exceeding toxic limits. Run-off of fecal coliform bacteria is regularly limiting the harvestability of shellfish such as oysters, due to ensuing health risks.

Mercury accumulation is presently limiting the consumption of some fish species. It has been reported that breeding success of for instance local pelican colonies could be influenced subsequently by this kind of pollution. Sugar cane growing and cattle raising produce an annual value of about 300 million dollar (in BTES!).

Other resources (Oil, Gas)

The Louisiana coastal zone had rich resources in natural oil and gas. The production of oil and gas has decreased about a factor 4 between 1990 and 2001. Oil production has been moved to offshore, where large reserves are exploited. The oil industry has developed a lot of refining and chemical infrastructure in the coastal area, to provide a link between oil production sites and transport networks of produce inland. Inshore production value was about 1000 million dollar in 2001. This coastal network transports 30% of the nation's gas and oil supply. 80% of USA offshore production is transported through the Louisiana coastal zone. 50% of the USA refinery capacity is located in this area. The exploitation of these resources has influenced the landscape considerably. Many channels have been dredged through the marshes to access drilling stations and enable construction of pipe lines. This has changed water circulation and salinity gradients in many areas of the delta. Subsidence could have been accelerated by oil and gas extraction (a proven impact of natural gas extraction is in the Dutch Wadden Sea of the Netherlands where the seabed subsided at places about 30 cm after gas extraction).

Main issues and trends

Pollution (oil, chemicals, nutrients)

The nutrient load being discharged by the Mississippi has produced a regular hypoxia in the Gulf of Mexico, killing all non mobile species and some fish every summer season. The area of the 'dead zone' is about 21,000 km^2. It stretches along the entire coast of Louisiana. This nutrient load is produced by intensive agriculture practices upstream in the Mississippi basin. In some years, 'dead zone' enters the nearshore shallow waters, killing many animals. Restoration of the lost filtering function of fresh, brackish and salty wetlands for Mississippi river water will help reduce this phenomenon. Yearly about 3000 oil or chemical spills are recorded along the Louisiana coastline by the Coast Guard Marine Safety Office.

Changed water circulation and salinity cause biotope switching

Construction of shipping channels has promoted the intrusion of saline water into formerly fresh parts of estuaries. The MRGO canal brings saline water into Lake Pontchartrain, causing considerable mortality of local fauna and flora. The Houma shipping channel and channels dredged for oil exploration have the same effect. Salt marsh erosion is allowing saline waters to flow further into estuaries and is now threatening the drinking water quality of people living in the Southern parts of the bayous. Switching between biotopes is caused by the same processes. Large-scale infrastructure parallel to the coast such as highways and railways has disturbed the normal flow of water in many. This has caused changes in the health of existing biotopes that have become either too fresh or too saline, or have experienced changes in inundation regimes.
Known from historical times, massive oyster reefs in front of the coastal zone have now disappeared because of changes in water discharge and salinity gradients.

Oyster squeeze

The best-known mollusk in Louisiana estuaries is the eastern oyster, which has been extensively studied because of its commercial importance. At the seaward end of the estuary, oysters are being pushed inland by encroaching saltwater, which favors oyster predators and parasites. Conner and Day (1987) cited evidence that most of the observed summer oyster deaths in the lower (more saline) estuary are related to the protozoan *Perkinsus marinus* rather than to predators such as conchs, stone crabs, boring sponges, and oyster piddocks. At the landward end of the estuary, oysters are being pushed seaward by pollution from developed areas (Van Sickle et al. 1976; Kilgen et al. 1985). Despite this squeeze, the area of substrate potentially suitable for eastern oyster production is increasing as wetlands degrade, and the area leased for oyster production is also increasing (Condrey et al. 1995).

Saltmarsh subsidence, eat-out and erosion

Compaction of subsoil and sea level rise are an important causes of relative subsidence. Oil and gas extraction add an unknown fraction. Saltmarshes and levees get waterlogged and this influences the mortality of species. For instance many oak trees on levees in the Southern part of the delta are now dying or dead. Due to waterlogging. Saltmarsh vegetation is sensitive to chemical changes in the subsoil that are caused by waterlogging. In addition, the introduction of an exotic mammal species (Nuria) is causing overgrazing of saltmarshes resulting in mortality. Once a saltmarsh patch has died off, stability is lost and erosion is more rapid. Increase of larger open water surfaces will allow more waves and higher current speeds. This will increase erosion. A positive feedback loop is created.

Hydrocarbon and formation water production

Various studies of induced subsidence in the Gulf Coast region demonstrated that reductions in land elevation can occur either directly above the producing formation or several kilometers away from producing wells (Gustavson and Kreitler 1976; Ewing 1985; White and Morton 1997). At some of the investigated sites, the locus of subsidence and land loss was controlled by the coupling between reservoir compaction and slip along growth faults that become active when sufficiently large volumes of fluid (oil, gas, formation water) were

removed from the subsurface (Figure 31). Fluid extraction may cause a decline in pore pressure within the rocks and alter the state of stress near the faults (Geertsma 1973). Thus, both the pattern of hydrocarbon production (reservoir geometries) and fault-plane geometries need to be considered in predicting the location and magnitude of subsidence (Chan 2005).

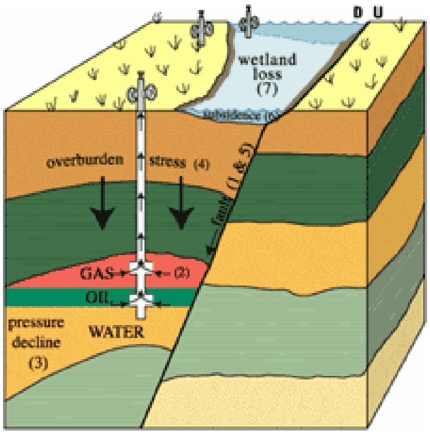


Figure 31 Possible effects of petroleum production. Prolonged or rapid production of oil, gas, and formation water (2) causes subsurface formation pressures to decline (3). The lowered pressures (3) increase the effective stress of the overburden (4), which causes compaction of the reservoir rocks and may cause formerly active faults (1) to be reactivated (5). Either compaction of the strata or downward displacement along faults can cause land-surface subsidence (6). Where subsidence and fault reactivation occur in wetland areas, the wetlands typically are submerged and changed to open water (7). Figure is not to scale. D, down; U, up. (Ref: Morton et. al., 2006).

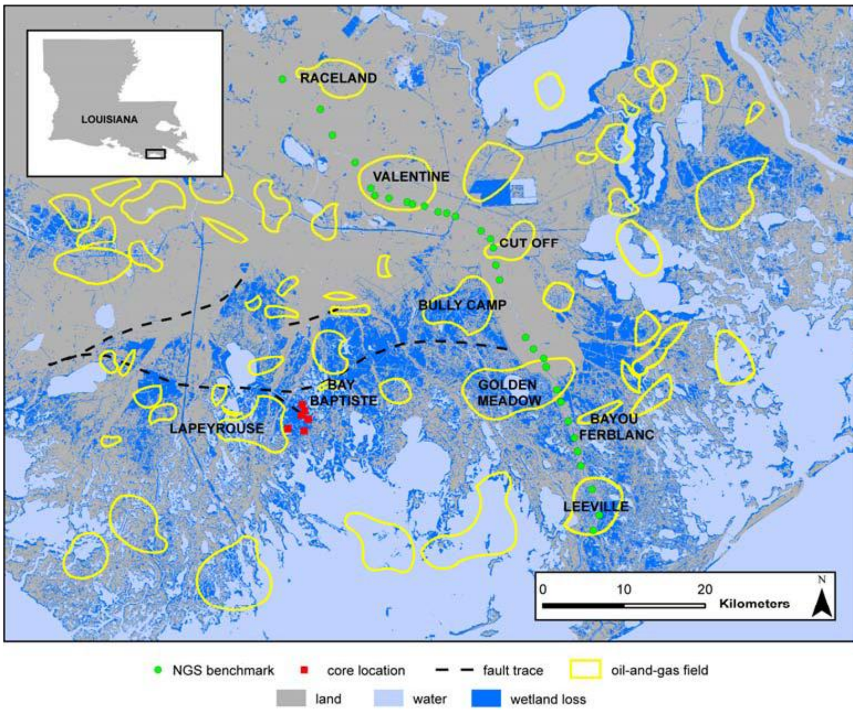


Figure 32 Map of South Louisiana showing data sets near and along Louisiana Highway 1 between Raceland and Leeville, including locations of benchmarks along Louisiana Highway 1 (green circles), oil and gas fields, wetland losses, and cores from the Madison Bay study area (red squares). Fault projection from Kuecher and others (2001); wetland losses from Morton and others (2005); outlines of producing fields modified from Morton and Purcell (2001). (Ref: Morton et. al., 2006).

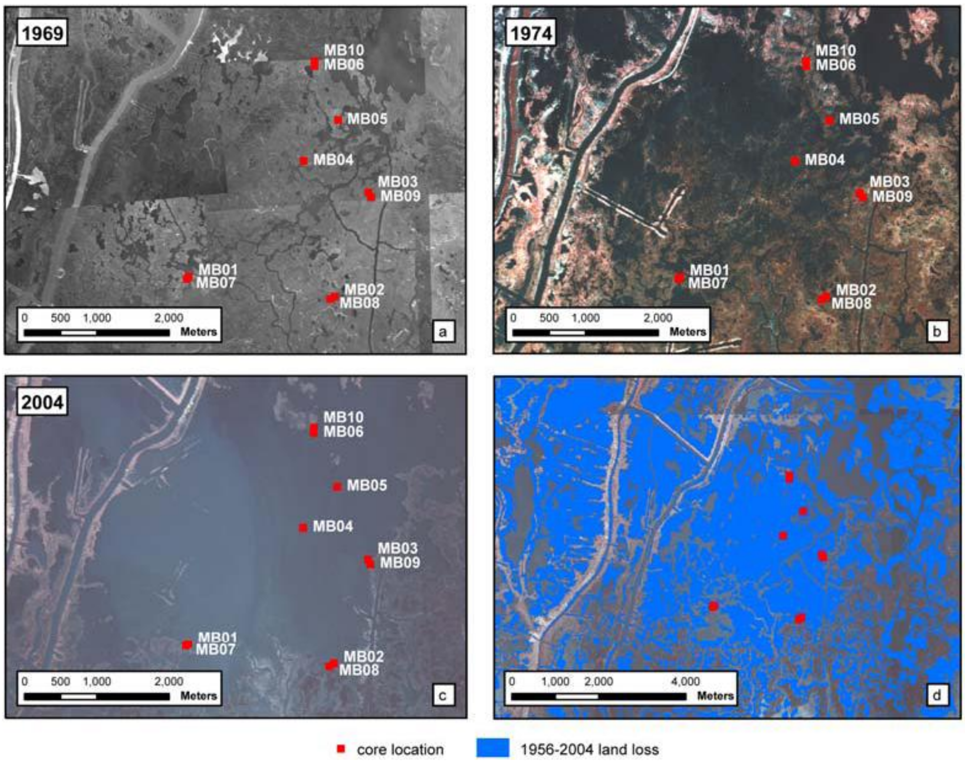


Figure 33 Locations of sediment cores and stratigraphic cross sections from the Madison Bay area superimposed on pre- and post-subsidence aerial photographs taken in (a) 1969, (b) 1974, and (c) 2004. (d) 1956-2004 wetland loss at Madison Bay and the surrounding area superimposed on the 2004 image. The photos show that wetlands above the field were healthy and continuous in 1969, but deteriorated and had converted mostly to open water by 1974. The rapid changes likely were caused by induced subsidence and fault reactivation resulting from hydrocarbon production. Modified from Morton and others (2005). (Ref: Morton et. al., 2006).

Rates of wetland loss in the 1990s and early 2000s were slower than when the wetlands collapsed between the 1960s and 1980s. The deceleration in rates of wetland loss, which corresponds with the rapid decline in hydrocarbon production, could signal a reduction in the underlying rates of subsidence.

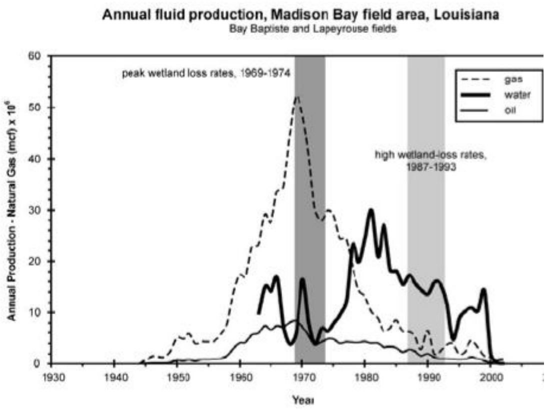


Figure 34 Cumulative hydrocarbon production in the Lapeyrouse and Bay Baptiste Fields, Louisiana from 1944 to 2002. Compare with production history with changes in wetlands observed in air photos at nearby Madison Bay. Production data from the Louisiana Department of Natural Resources and the PI/Dwights PLUS Database (HIS Energy 2003). Wetlands began rapidly disappearing after the field begain rapidly producing large volumes of hydrocarbons in the 1960s. Wetland loss generally slowed when hydrocarbon production rates declined. Wetland loss also was rapid in the late 1080s and early 1990s following a peak period of formation water production. Modified from Morton and others (2005).

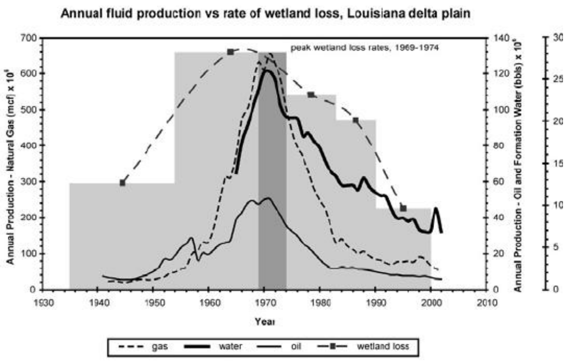


Figure 35 Composite histories of fluid production from oil-and-gas fields and wetland loss in South Louisiana. Production data from the Louisiana Department of Natural Resources and the PI/Dwights PLUS Database (HIS Energy 2003). Wetland loss values were determined by Britisch and Dunbar (1993) and John Barras (unpublished data). These historical data, integrated across the delta plain, show close temporal and spatial correlations between rates of wetland loss and rates of fluid production. From Morton and others (2005).

References

- Morton et al. 2006. Evidence of regional subsidence and associated interior wetland loss induced by hydrocarbon production, Gulf Coast region, USA (http://coastal.er.usgs.gov/gc-subsidence/regional_subsidence.pdf).
- Subsidence and Fault Activation Related to Fluid Energy Production, Gulf Coast Basin Project.
- Constraining Rates and Trends of Historical Wetland Loss, Mississippi River Delta Plain, South-Central Louisiana - originally appeared as a paper in *Coastal Environment and Water Quality - Proceedings of the AIH 25th Anniversary Meeting and International Conference "Challenges in Coastal Hydrology and Water Quality"* (2006)
- Evidence of regional subsidence and associated interior wetland loss induced by hydrocarbon production, Gulf Coast region, USA - originally appeared as an article in *Environmental Geology* (2006)
- Historical Subsidence and Wetland Loss in the Mississippi Delta Plain - originally appeared as an article in *Gulf Coast Association of Geological Societies Transactions* (2005)
- Rapid Subsidence and Historical Wetland Loss in the Mississippi Delta Plain: Likely Causes and Future Implications - USGS Open File Report 2005-1216
- Causes of hot-spot wetland loss in the Mississippi delta plain - originally appeared as an article in *Environmental Geosciences*
- Probable Production Induced Subsidence, Fault Reactivation, and Wetland Loss in the Gulf Coast Region - Presentation by USGS scientist Robert Morton

- Subsurface Controls on Historical Subsidence Rates and Associated Wetland Loss in Southcentral Louisiana - originally appeared as an article in *Gulf Coast Association of Geological Societies Transactions*
- Primary Causes of Wetland Loss at Madison Bay, Terrebonne Parish, Louisiana - USGS Open File Report 03-60
- Shallow Stratigraphic Evidence of Subsidence and Faulting Induced by Hydrocarbon Production in Coastal Southeast Texas - USGS Open File Report 01-274
- Wetland Subsidence, Fault Reactivation, and Hydrocarbon Production in the U.S. Gulf Coast Region - USGS Fact Sheet FS-091-01
- Wang, F.C., 1977. Dynamics of intertidal marshes near shallow estuaries in Louisiana. Wetlands Ecology and Management. Volume 5, Number 2 / June, 1997, pp 131-143. 10.1023/ A:1008255609987. Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, Louisiana, 70803-7503, U.S.A.

Impact of canal construction

Canals currently comprise about 2.5 percent of the total coastal surface area in Louisiana (Craig et al. 1980; Turner et al. 1982), and the percentage has been accelerating through time. Historically, canals have been dug for drainage and access. Today the greatest share of canalization is attributed to the oil and gas industry (Figure 36). In 1984, 70 to 80 percent of the coastal management permits issued for canals were for oil and gas activities. The primary reasons for the myriad of canals in the Louisiana coastal zone include navigation, pipeline routes, and access to drilling sites. Although dredging canals has only directly converted 2.5 percent of the wetlands to open water, their impact is much greater. Spoil banks composed of the material dredged from the canals tend to smother adjacent marshes, converting wetlands to uplands, often interrupting natural hydrologic processes, and blocking the distribution of sediment. Canals oriented perpendicular to water flow tend to impound water and reduce sediment availability, and ponding of water can drown a marsh. Canals parallel to water flow tend to lessen freshwater retention time and allow greater inland penetration of saltwater. Turner et al. 1982) estimate that as much as 90 percent of Louisiana's land loss can be attributed to canals. (after EPA-230-02-87-026, Saving Louisiana's Coastal Wetlands, April 1987)

A linear relationship exists between canal density and marsh loss rate (Turner et al. 1982; Turner and Cahoon 1987a,b,c), although there is considerable unexplained variation in the data, and therefore, considerable controversy surrounds the effect of canals on marsh loss. The rate of loss per unit of canal is higher in recently formed deltas where the sediments are less consolidated (Deegan et al. 1983), and it seems to be highest where freshwater marshes experience salt intrusion (Dozier 1983). Turner et al. (1982) found that in places where canal density was zero, marsh loss was always less than 10% of the total loss and was usually nearly zero. This finding indicates that if there were no canals, the marsh loss rate would be less than 10% of the present rate. The area actually dredged out of the marsh for a canal is less than 10% of the total loss. If the spoil area is three to five times the size of the canal area (Johnson and Gosselink 1982), the direct loss of marsh due to canals is less than half of the total loss. The rest of the loss is attributed to indirect effects of circulation disruption by the canal and its spoil deposits, unintended impoundment of wetlands, and saltwater intrusion into freshwater wetlands (Turner 1987; Turner and Cahoon 1987a,b,c). (after http://biology.usgs.gov/s+t/SNT/noframe/gc138.htm)

Figure 36 Canals dug in Louisiana's coastal marshes for oil and gas drilling and production operations.

A three-year (1991–1993) field investigation was conducted to quantify the hydrodynamics of intertidal marshes adjacent to tidal channels and shallow bays within two Louisiana coastal regions: (1) the sediment-rich Atchafalaya Basin, and, (2) the sediment-poor Terrebonne Basin with relatively minor riverine inflow. The Terrebonne Basin marsh is regularly inundated and flooding is characterized by sporadic draining interspersed by prolonged flooding events. The maximum water depth on the marsh surface exceeds 50 cm, the flow velocity across marsh surface reaches 10 cm/s, and the sediment deposition rate varies from 10 to 90 g/m^2 per tidal cycle. This rather high sediment deposition rate occurs during winter storms with strong Southerly winds. In contrast, the marsh site within the sediment-rich Atchafalaya Basin is irregularly inundated and characterized by sporadic flooding interspersed by prolonged draining. There the marsh flooding depth rarely exceeds 25 cm, the over-marsh flow velocity barely reaches 2.5 cm/s, and the sediment deposition rate ranges from 5 to 50 g/m^2 per tidal cycle. The surprisingly low rate of sediment deposition in a marsh within a sediment-rich region is largely due to the man-made canals that alter the hydrologic regime in the upper reaches of the tidal channel. (after Wang, 1977).

Backfilling canals to restore Louisiana wetlands.

Canals have been built for access and transport of oil, which has been extracted from the coastal area. One restoration technique being utilized is backfilling of canals once they have been abandoned by the oil companies.

Canals are dredged to a depth of 2.5 m and range from 100 m to 1,000 m in length, some extending from the Gulf of Mexico to the entire length of the coastal shoreline (Turner et al. 1994). They are built because natural channels are not deep enough, nor are they located conveniently for industry requirements. The Louisiana delta area is now laced with thousands of these interconnecting channels.

When the canals are built, the dredged material is thrown up along the side, creating what is called a spoil bank. Spoil banks consist of marsh soil and organic material. As the banks settle, they create a levy that runs along the length of the canal.

Estimates show that for every mile of canal built, 30 to 40 acres of marsh are degraded or buried under the spoil banks (Connor et al. 1987). Spoil banks disrupt the natural source of sediments needed for accretion and block overland flow. Although re-vegetation does occur, species composition changes, creating shrubs and small trees as a result of the higher elevation of the spoil banks (Craig et al. 1980).

The levies created by the spoil banks not only alter the natural hydrological flow, but can also block migration of aquatic organisms. Studies have also shown that certain aquatic species migrate up and inhabit back marshes during their juvenile state, then return to the sea for their adult life (Reed et al. 1994). Because the canals are deeper than the surrounding wetlands, they allow larger predators to enter areas inhabited by juvenile fish. Marked declines in fish catch by some Louisiana commercial fishing industries have been noted as a direct result of predation and loss of migratorial passageways.

Tides enter and leave through the canals at a greater velocity than through undisturbed marsh, resulting in erosion and widening of the banks. Annual increases in canal widening range between 2 to 14% (Craig et al. 1980). Saline water travels up the canals, invading deep into freshwater territory, causing vegetation to die and creating open water where dense vegetation previously existed. The greatest impact on wetland destruction has been noted in saline and brackish marshes. Besides the deepening and widening of the canals through tidal erosion, these marshes are hit the hardest by coastal storms, making them less effective as storm buffers for the inland coast.

Where nutrient-laden sediments would naturally trickle slowly through the wetlands, canals reroute it to lakes and ponds, causing an increase in eutrophication. Canals are, therefore, directly linked to loss of wildlife habitat, and to the decrease in the effectiveness of the marsh as a natural water purifying system (Craig et al. 1980). (After Leanne Lemire (http://horticulture.coafes.umn.edu/vd/h5015/97papers/lemire.html).

C.3 Saltmarsh dynamics

Introduction

In order to provide sound solutions to cope with the loss of marshland in the Louisiana coastal zone, its cause should be thoroughly understood. Furthermore, levee construction in this environment is also dependent on the rates of subsidence that can be expected for the next decades and centuries. This text is a literal compilation of what could be found through sources on the internet. The background report is available as a separate product.

Land Loss

Text to be added.

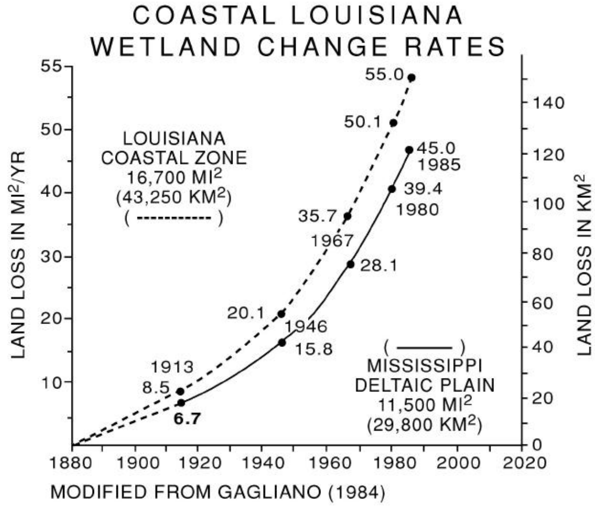


Figure 37 Rates of wetland loss in the Louisiana coastal zone compared with loss in Mississippi Deltaic Plain.

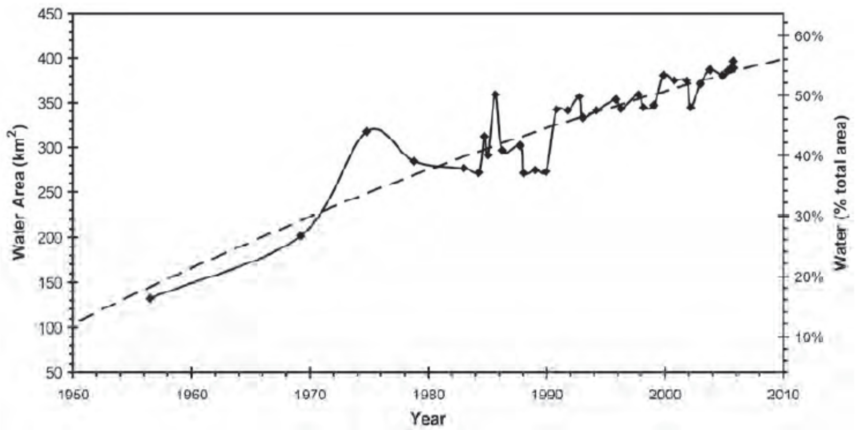


Figure 38 Composite historical water are from 1956 to 2005 for the Bay St. Elaine, Madison Bay, DeLarge, Pointe au Chien, and Bully Camp wetland-loss hotspots. Although water-area fluctuations are evident, the trend line shows a general increase in open water are through time, indicating continued wetland loss.

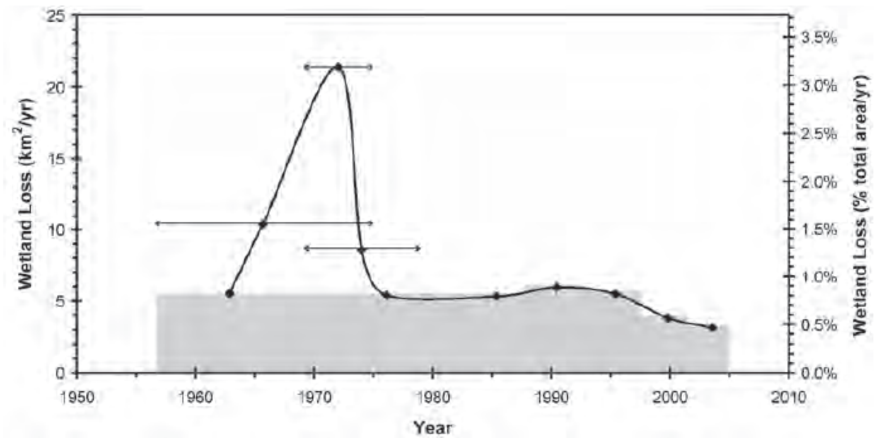


Figure 39 Rate of wetland loss for the combined study area from 1956 to 2005. The post-1983 rates were calculated from Landsat TM imagery acquired on dates for which the daily, previous day, and 3- and 7-day running average water levels at the Grand Isle, Louisiana tide gauge (NOS #8761724) were within one standard deviation of the mean water-level trend line. Peak wetland-loss rates are two to four times higher than the pre- and post-1970s background rates.

Land gain

Text to be added.

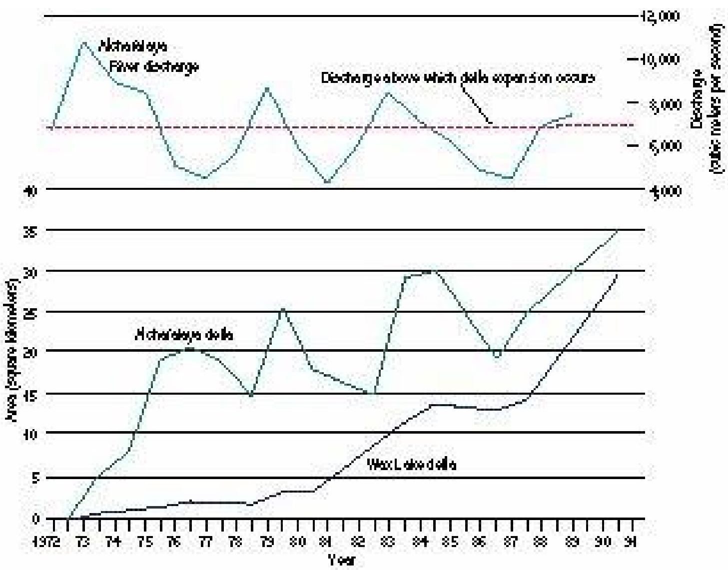


Figure 40 The relationship of growth of the Atchafalaya and Wax Lake deltas to river discharge. (http://biology.usgs.gov/s+t/SNT/noframe/gc138.htm)

Barrier island restoration using dredging spoils

Thus far the most extensive land loss has occurred in the Barataria basin and around Terrebonne Bay in an area South of New Orleans and West of the Mississippi. Not surprisingly, the barrier islands protecting this region have deteriorated to an alarming extent and are in need of restoration. The Isles Dernieres barrier island chain, which protects Terrebonne Bay, is one of the most rapidly deteriorating barrier shorelines in the United States and for the most part is unable to perform its shore protection function.

Chain breakup has resulted both from major storm actions and from the loss of nourishing sediment from the natural system. Whiskey Island, a representative part of the Isles Dernieres chain, lost an average of 31.1 acres (12.6 ha) per year from 1978 to 1988.

One source of new sediment for restoring the Isles Dernieres chain is Ship Shoal. In April 2004 the Minerals Management Service of the U.S. Department of the Interior issued an environmental assessment dealing with the issuance of noncompetitive leases for using outer continental shelf sand resources from Ship Shoal to replenish the coast and barrier islands. This assessment considered the effects on sensitive coastal and near-shore resources of the mining of approximately 14 million cu yd (11 million m^3) of outer continental shelf sand. The processes evaluated would use either a trailing suction hopper dredge or a cutterhead suction dredge to place the sand either on barrier islands for restoration or into temporary storage for later use as a construction material.

Ship Shoal is a submerged remnant of an ancient barrier island arc that lies about 10 mi (16 km) South of the Isles Dernieres chain. The shoal is about 31 mi (50 km) long and 3 mi (5 km) wide, with a relief up to 12 ft (3.6 m). The water between Ship Shoal and the barrier islands is no deeper than about 32 ft (9.7 m), and for most of the way its depth is less than 20 ft (6 m). This would hamper the use of large hopper dredges and large transport barges. Coastal engineers will have to decide between long-distance pumping in a 10 mi (16 km) pipeline with booster stations and some combination of hoppers, barges, and shorter pipelines.

Marsh Management (EPA-230-02-87-026)

The term ‘marsh management’ refers to a variety of activities. The philosophy behind this approach is that human activities have so disrupted the natural wetland system that the best hope for maintaining these ecosystems is for society to step in and limit further damage. The most common form of marsh management in Louisiana is to regulate the flow of water in and out of the marsh, with the general goal of limiting salinity and controlling water levels, and to plant vegetation. Such schemes typically involve regulating water flow in or out of wetland management units ranging in size from several acres to about five thousand acres. Wetland tracts larger than this are difficult to manage and are often partitioned into smaller units. Water flow is regulated by a system of retaining levees and some form of water control structure. Commonly used structures include fixed- and variable-crest weirs, single- and double-flapgated culverts, and sluice gates. These structures can be operated to allow juvenile marine organisms some access to internally managed wetlands for use as nursery and feeding areas. Other management schemes involving forced drainage (mechanical pumping) to regulate water levels may prevent marine organisms from using managed areas. Currently, forced drainage is limited to populated areas.

Though goals of individual marsh management plans may vary widely, most plans usually incorporate features that enable control of water levels and salinity by preventing inflow of excess saltwater and by regulating freshwater output or inputs (rainfall, runoff, or introduced freshwater) until the desired water level or salinity is reached. Examples of wetland areas utilizing passive (gravity-operated) marsh management schemes include much of the state-owned Department of Wildlife and Fisheries refuges and numerous privately maintained marsh tracts.

These areas are often managed to optimize vegetation growth and to maintain water level conditions best suited for waterfowl that winter in these wetlands. Management of commercial crawfish ponds and other aquacultural efforts typically involves active pumping to achieve desired water levels. An important advantage of this approach (as well as wetland restoration) is that major landowners can implement these measures themselves. Since conversion of land to open water can deprive them of income from mineral extraction, fishing, hunting, and trapping, landowners often have an incentive to manage their marshes without help from the public sector. However, because federal activities that have benefited all of society have contributed to much of the wetland loss, an argument can be advanced for public subsidies of these activities. This may be particularly advantageous if such subsidies would result in more wetland protection than equivalent expenditures for federal, state, and local wetland protection projects. Although the recent reform of the federal tax code suggests that new federal tax incentives are unlikely, the current code permits deduction of contributions to conservation groups that restore or protect wetlands. The restoration potential of these measures is also limited. Most important, as relative sea level rises, passive management of water flow will become increasingly difficult. While tidal gates and gravity may be sufficient to adequately drain wetlands today, if sea level rises a few more feet, it will be necessary to actively pump the water out.

Terrebonne Parish is considering a plan for long-term marsh management. A tidal surge levee through the interior of the parish would be built, and marsh inland of that levee would be actively managed by forced and gravity drainage, even after the sea has risen a few feet above the marsh. The parish estimates the cost at over $100 million. This plan, however, would only be a partial solution. Although birds, animals, and some fish would benefit from the protected vegetation, active pumping systems currently do not allow shrimp and other marine organisms to pass from one side of the levee to the other. Until cross-levee migration becomes possible, this approach would do less to benefit commercial fisheries than other methods of protecting an equivalent number of acres. Nevertheless, it might be more practical than increasing sediment supplies in places that are far from active distributaries such as eastern Terrebonne Parish, particularly if sea level rise accelerates.

A final marsh management technique involves periodic spraying of sediment on the marsh to increase its rate of vertical accretion. Technologies to accomplish this goal have only recently emerged, and have some of the same logistical and cost problems as marsh creation. In spite of these difficulties, this technique may prove useful in certain areas that are just barely being submerged due to a sediment deficit. Clearly, it would be far cheaper to supply sediment to an existing, living marsh than to fill a bay to the level necessary to create a new marsh; it would also disrupt ecosystems less. (This practice is being applied to a limited extent to marsh adjacent to new canals in Terrebonne Parish.)

Table 1 Potential wetland acreage saved by two proposed freshwater diversion structures (acres). Source: USACE, 1984)

	Barataria	**Breton Sound**
1985 Acreage	430,500	182,900
Remaining wetland by 2035 (assuming current rates of sea level rise)		
Without Diversion	245,100	131,400
With Diversion	327,800	147,800

Restoring a portion of freshwater flows to the marshes will also remove some of the nutrients the water carries from the main stream of the Mississippi. This will have the fringe benefit of lowering the nutrient flow, mainly caused by agricultural fertilizer runoff, that enters the Gulf of Mexico. Ultimately, this could significantly reduce hypoxia in the Gulf.

As engineers seek to create larger diversions, however, they will confront several challenging questions. Is gravity flow in the river's natural channels sufficient, or will a system of pumps and channels be required? Can hydraulic engineers model sheet flow over miles of marsh and predict its effect on salinity and infrastructure? What is the best method of dealing with property that will be reintroduced into the floodplain by these diversions? As engineers discover answers to questions of this type, they must be willing to adapt their strategies to reflect the new knowledge.

Management and restoration of marshes are methods proposed for slowing coastal marsh loss. Major components of marsh management are altering water levels, manipulating burning regimes, managing grazing animals, controlling water quality entering areas, and influencing effects of tidal flows. Manipulating water levels is believed to be the overriding factor in determining wetland character and integrity.

‘Structural marsh management’ is the use of levees, natural landscape features, and water control structures to give human control of water movement in an area. This technique is an old one, having been practiced for over two centuries; however, the full range of consequences is still poorly understood.

Canal damage remediation techniques

After: Lemire, L. Backfilling canals to restore Louisiana wetlands. (http://horticulture.coafes.umn.edu/vd/ h5015/97papers/lemire.html).

Controlled Diversion: One proposed mitigation techniques was to allow USACE to divert some of the Mississippi River into a controlled area, creating a new delta (Craig et al. 1987). This diversion could create more wildlife habitat and could potentially improve fisheries. This would require prior planning, operational experience and ongoing management. Although the cost and efficiency would have been low, there was a great deal of concern regarding the concentrations of heavy metals and pesticides in both the water and sediment. This potential project was put on hold pending further investigation.

Reuse of Spoil: A 5-year research project was conducted by USACE to reuse material from spoil banks. Some suggestions included deposition as a substrate for wildlife habitat, beach renewal, restoration of bare ground, road construction material and sanitary land filling. The study concluded that spoil material used as a biologically productive substance could be effective and the results could be accurately measured (Craig et al. 1987). Although this alternative could be used as a post-remedial action, it would not halt the ongoing loss from continued dredging and canal building.

Regulatory Controls: Regulatory controls have the advantage of affecting the entire coastal zone area. It requires builders comply with standardized practices. Controls suggested include (1) standardizing the depth of canals and requiring companies to backfill them once they were no longer in use, (2) prohibiting new canal construction, (3) minimizing new canal construction by the use of existing canals, (4) plugging pipeline canals with earthen or shell dams (plugs) wherever possible, (5) no new wetland impoundments, (6) avoiding or eliminating residential development on wetlands, and (7) reserving spoil material to build new marshes. While these methods would not eliminate past damage, but further wetland destruction would be halted.

Saltwater Intrusion Remediation: Remediation efforts have been suggested to reduce the impact of saltwater intrusion. Impoundment or semi-impoundment by constructing low levies with spoil material close to the marsh edge to limit water exchange. Little is known about this technique's long term effectiveness. Impoundments do not allow for fish migration. Studies have also shown that hurricanes have a more devastating effect on impounded areas than on natural marshes. A second suggestion was to divert freshwater into the marshes to reduce salinity. A third option to restore the natural hydrology of the wetland system was to permanently close some canals, and to install locks in navigation channels.

Backfilling Canals: The most important of the five mitigation techniques was backfilling of the canals. In one study, 33 canals that had been abandoned by the oil industry were backfilled. The backfilling process consisted of bulldozing spoil banks back into the canals. Removing spoil from banks to encourage re-vegetation, and restoring the canal depth to its natural state. After backfilling was completed, return visits were routinely done. Sediment deposition and loss was measured, as was canal depth and width (Turner et al. 1994).

The cost of this backfilling project was in the range of $1,200 to $3,400 per hectare. In contrast, building of the original canals were constructed at an average cost of $25,000. Other positive aspects of this technique were that costly equipment was not required and there was no further on-site management required. Once backfilling was completed, the area was left for natural processes to take their course.

Some factors considered for the backfilling project were (1) soils, (2) vegetative cover, and (3) fish utilization. Fish utilization related to canal length, canal age, marsh soil organic matter content, and the presence or absence of a plug at the mouth of the canal (Turner et al. 1994).

The results of backfilling have been effective. Although some canal delineation is still discernible, the edges of the spoil banks are becoming more irregular. Re-vegetation is occurring on spoil banks, although if the elevation was too high, there was a change in species.

Dendritic drainage patterns have reestablished and have begun to revert back to their natural hydrologic flow, especially in areas where no plug was in evidence. Where plugs were intact, wildlife and fish habitats were created but did not allow for migratory aquatic species. In addition, deposition of sediments and nutrients were not apparent.

Some of the most significant factors that influenced the success of the backfilling project was the canal length and whether or not sufficient amount of spoil material was returned to the canal. These factors were directly related to the experience of the dredge operator. Putting the correct amount of spoil material back in the canal without gouging the marsh or causing the marsh elevation to be too high or too low, was a key factor. Because there are so few skilled operators, it was difficult to get consistent results.

Backfilling as a restoration technique to manage abandoned canals is easy, cost effective and does not require further on-site management. The area becomes re-vegetated, and erosion is halted. The natural hydrology is restored and fish and wildlife become more abundant. As more abandoned canal sites become available, more opportunities will be available for future wetland restoration.

Concepts for Large-scale Restoration in Coastal Louisiana Using Long Distance Conveyance of Dredged Material

After: Reed, D.J., 2004. Concepts for Large-scale Restoration in Coastal Louisiana Using Long Distance Conveyance of Dredged Material.
http://www.epa.gov/earth1r6/6wq/ecopro/em/cwppra/b_dupont/long_distance_conveyance12_04.pdf

Proposed measures: Marshland restoration

Natural process solutions, such as diversions, would introduce new sediments into the system, but gradually over many years, and larger diversions would dramatically alter the salinity regime of the basins (USACE, 2004). There are also concerns regarding the fate of nutrients introduced with the river waters and the potential for eutrophication and perhaps harmful algal blooms. The introduction of new sediments into the estuarine basins could also be achieved through long-distance pipeline conveyance of dredged materials. A workshop held in October 2003 (Hales et al., 2003) focused on the conveyance technology and clarified for many in the Louisiana restoration community that the movement of dredged material many miles across the coast to areas of need was technologically feasible. Concerns remained, however, regarding the use of large quantities of dredged material to create functional marsh habitat on a large scale (i.e., thousands of acres).

Planned and implemented measures for curtailing wetland loss (EPA-230-02-87-026)

The possible options for curtailing wetland loss are numerous. They include diverting freshwater and sediment into the marshes; changing the course of the Mississippi River; modifying patterns of water and sediment flow to the marshes; maintaining wetlands artificially; restoring the barrier islands; and shifting away from the types of canals, channels, and levees that have destroyed wetlands to alternative transportation and flood protection strategies that have less adverse environmental impacts. This section briefly describes each of these measures.

Table 2 lists several of the options that have been proposed for curtailing wetland loss; Table 3 lists the measures that have been authorized by the Louisiana Legislature, planned by the Louisiana Geological Survey, or constructed by other organizations.

Table 2 Options for Curtailing Wetland Loss

Options for Curtailing Wetland Loss
Barrier Island Restoration, Marsh Building and Restoration
1. Restore leveed, drained, dredged wetlands 2. Build marsh with materials from dredging projects instead of re-suspending dredged material in the lower river or creating spoil banks. 3. Require offsetting marsh creation for wetlands conversion due to development. 4. Raise the elevation, seal breaches, re-nourish beaches of barrier islands
Marsh Management
1. Construct tidal barriers and otherwise manage flow of water to and from marsh 2. Levee wetlands and manage artificially. 3. Thin layer deposition 4. Regulate marsh fires 5. Restore suitable marsh vegetation
Regulatory
1. Limit creation of new canals 2. Fill existing canals 3. Limit boat speeds in waterways 4. Restrict marsh buggies 5. Require mitigation for private wetland destruction 6. Subsidize new technologies
Diversion
1. Increase flow through the Atchafalaya River 2. Freshwater and/or sediment diversion to wetlands 3. Diversion to Mississippi River Gulf Outlet 4. Increase water flow to Bayou LaFourche 5. Separation of navigation from river flow using locks 6. Avoidance of additional levee construction in lower Atchafalaya

Table 3 Authorized, Planned, and Completed Projects for Curtailing Wetland Loss

Authorized, Planned, and Completed Projects for Curtailing Wetland Loss
Authorized by Louisiana Legislature (funded)
(1) Restore barrier islands and shorelines (a) Isles Dernieres (b) Fourchon Island (c) Shell Island (d) Timbalier/E. Timbalier Islands (e) Holly Beach (f) Grand Isle (USACE) (2) Diversion (a) Caernarvon Diversion (joint state/federal project) (b) Pass a Loutre Marsh Creation (small diversion pilot project) (3) Marsh Management (a) Montegut-Terrebonne (b) St. Bernard Parish (c) St. Charles Parish-LaBranche Wetlands

Authorized, Planned, and Completed Projects for Curtailing Wetland Loss
Planned by Louisiana Geological Survey (presently unfunded)
(1) Barrier Island/Shoreline Restoration and Nourishment (a) Plaquemines Parish Barrier Shorelines (b) Timbalier/E. Timbalier (c) Holly Beach-Cameron Parish (d) Caminada-Moreau shoreline (2) Diversion (joint federal/state projects) (a) Davis Pond (*http://www.pubs.asce.org/ceonline/ceonline04/0704feat.html*) When the Davis Pond facility was completed in 2002 at a cost of $119.6 million, it ranked as the world's largest freshwater diversion project. By releasing up to 10,650 cfs (300 m^3/s) of freshwater, it is designed to simulate the floods that used to occur there in the spring and to convey sediment and nutrients from the Mississippi River into a 9,300 acre (3,800 ha) ponding area in the Barataria Bay basin. Water release is controlled in response to basin salinity levels and fish and wildlife resources. The diversion structure consists of a 535 ft (163 m) long, 85 ft (26 m) wide inflow channel; four 14 ft (4.3 m) square iron-gated culverts extending through the river levee; and an 11,000 ft (3,350 m) long, 120 ft (37 m) wide outflow channel. USACE estimates that, over the next 50 years, Davis Pond will preserve about 33,000 acres (13,000 ha) of wetlands and benefit 777,000 acres (315,000 ha) of marshes and bays. The estuary served by the project provides nesting areas for migratory waterfowl and hosts economically important oyster beds, shrimp and fish nurseries, and habitats for fur-bearing animals. The Davis Pond project is expected to generate annual benefits totaling $15 million. (b) Bonnet Carre (3) Large Scale Wetland Protection Program (Outgrowth of this Study)
Completed by Other Agencies
(1) Barrier Island/Shoreline Restoration and Nourishment (a) Eastern Isles Dernieres Restoration (Terrebonne) (b) Timbalier Island Repair Project (Texaco, Inc.) (c) Grand Isle Hurricane Protection Levee (USACE) (2) Marsh Management (numerous individual land owners)

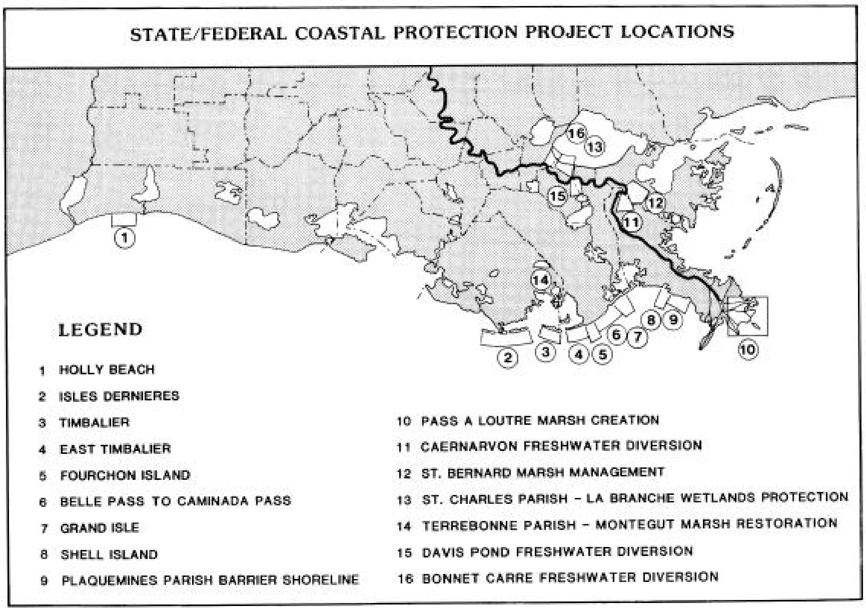


Figure 41 Map of coastal Louisiana depicting locations of state/federal coastal protection projects.

C.4 Restoration cost, who pays?

In February 2002 an interagency task force was set up in the USACE New Orleans offices. One of its primary purposes was to produce a comprehensive plan—the Louisiana Coastal Area (LCA) Louisiana Comprehensive Coastwide Ecosystem Restoration Study—that could be presented to Congress. The intent was to apply the same model that had been used to develop the Comprehensive Everglades Restoration Program (CERP). CERP, the largest environmental restoration program ever planned, had a price tag of $8 billion and comprised a number of projects designed to 'fix the plumbing' in South Florida and restore freshwater flows to the Everglades. For those concerned with the Louisiana coast, it seemed conceptually, philosophically, and politically an excellent model to follow.

The budget for fiscal year 2005 proposed by President Bush in February recognized the gravity and exigency of the situation in coastal Louisiana. Although the budget proposal did not expressly endorse a comprehensive restoration program conforming to the Everglades model, it did call for action and recognized that past development efforts have contributed to the loss of land, wetlands in particular. The following items are excerpted from the section of the budget proposal pertaining to USACE:

- In 2004, USACE will work to issue a draft report that identifies the most critical ecological needs and proposes a near-term program of highly cost-effective projects to address them. The report will also highlight the key long-term scientific uncertainties and engineering challenges facing the effort to protect and restore the ecosystem, and propose demonstration projects and studies to help answer these questions. The report will focus on the specific coastal areas that require the most immediate attention and on the best way to sequence the proposed work over the next 10 or so years, as to learn what works best.
- In 2004, USACE will begin developing studies of potentially promising, long-term ecosystem restoration concepts, with the objective of determining whether they would provide a cost-effective way to create coastal wetlands.
- An existing Federal-State Task Force established under 1990 legislation will increase its efforts to build and evaluate highly cost-effective freshwater and sediment diversion projects.

The budget message summarized the benefits of the approach this way: 'This coordinated approach to restoration combines a commitment to address the highest priority needs with a search for innovative solutions [emphasis added]. It also ensures that the coastal Louisiana restoration effort will, in the long-term, be able to adapt and evolve as needed, based on the best available science.'

As program development goes, the engineering community is poised for a major new effort in the Mississippi River basin. The problem is well defined: it is to reengineer the Mississippi. The conceptual solutions are clear, but the number of possible combinations of individual projects is daunting. The country needs a program of cost-effective projects to address the most pressing ecological dangers. In short, over the next decade engineers will be called upon to optimize and develop projects that can deliver environmental and economic benefits to coastal Louisiana.

Civil engineers must enter the policy discussion and be willing to rub shoulders with biologists, economists, and politicians to ensure that the solutions developed are practical and effective.

One of the most important conclusions of the summary report emerging from the Coastal Louisiana Technical Summit is the following: *While there are still scientific unknowns concerning the ecosystem of the Louisiana coast and the Mississippi River, considerable data and information have been gathered over the last two centuries and are available for use. Complete knowledge of the river and the coast will never be achieved. The amount of data and information that has been gathered is sufficient to proceed. Lack of information or data should not be used as a reason to delay work.*

This is a clarion call for the 21st century. American civil engineers know enough to get to work on reengineering the Mississippi River. It is time to start updating the tremendous work begun over a hundred years ago.

C.5 Tentative summary of findings on wetlands

- The cyclic geological development of the Mississippi Delta is the driver of a cycle of habitats and biodiversity at each location in the Delta, spanning many millenia. Nothing lasts forever. All lobes are in The present high biodiversity slow ‘deterioration-phase’ of the present delta-lobe naturally would be a part of this cycle. The Atchafalaya delta is an example of the natural fast growth-phases as part of the same cycle.
- Long term relative subsidence is estimated between 2-7 mm/yr. Main causes compaction, sea level rise, fault activation and post glacial land subsidence. Compaction rates are highest in the youngest deposits.
- Historic subsidence rates are measured at 12 mm/yr in the Miss. delta with increased rates between 1960-1990’s up to 30 mm/yr. As main new cause for subsidence oil and gas extraction is identified.
- At present subsidence rates (and marshland loss) seem to have slowed down again (according to Morton et al). This is suggested to be linked to depletion of hydrocarbon resources and therefore the gradual end of oil and gas production in the area.
- Marshland accretion rates are measured at 7-13 mm/yr, at least half of this accretion is from locally produced organic matter. Regularly flooded marshes accrete the most rapid and contain highest anorganic fractions. 1000 gr sediment can result in 1 cm/m^2 vertical marshland accretion. Natural accretion is therefore able to cope with long term subsidence rates and a little extra.
- Marshes close to streams and canals receive the highest sediment loads and therefore sustain higher accretion rates than backmarshes. High sediment loads produce increased nutrient availability and therefore also sustain higher productivity.
- Canal formation is considered as one of the most important causes of marshland loss. Canal formation has altered hydrodynamics. If this caused changed flooding frequencies, marsh accretion has been affected. Nutrients are flushed to the sea without being taken up in marshland vegetation. Fresh marshes are flooded less, because water is channeled more effectively toward the sea. Marshes in tidal areas could be flooded more frequently.

- Opening up of marshes is increasing erosion by increasing wave fetch and current speeds. Increasing flooding depth and frequency could compensate a little, by importing more sediment for marsh accretion.
- In addition, marsh browning disease and overgrazing by an exotic rodent is reducing marshland areas further.
- Main restoration options collected from various authors to restore marshlands in open water areas and broken marsh with few spoil banks are marshland creation and marshland nourishment. One could:
  - Enhance local sediment import and stabilization at the edge of open water areas in order to restore marshland horizontal extension.
  - Use long-distance pipeline conveyance of suitable dredged materials (fine fractions) to provide kick-start of marsh creation especially in combination with channel infilling.
  - Create river diversions provide restoration of hydrology and long-term marsh nourishment, but changes in salinity could conflict with dominant uses (such as oyster culturing)
  - Create subtidal barriers consisting of coarse materials to reduce fetch and storm surges, explore the possibility to combine this with protective oyster reefs.
  - Restore or create new shorelines to enhance the success of marsh nourishment and marsh creation in the leeward-areas. This can help to reconstruct salinity gradients inshore.
  - Create or restore islands to provide further reduction of fetch and restoration of bird breeding habitat.
- Main remediation actions to compensate marshland loss caused by canals are:
  - Plugging, isolating or backfilling of canals to restore hydrologic and salinity gradients;
  - Restoration of regular flooding to restore natural accretion rates by breaching of spoil banks.
- Manage rodent populations and marshland burning.
- Restore hydrology of impounded areas (for instance areas sealed off artificially by levees, by railway or roads).
- Use remaining spoil banks and other higher elevation features to stabilize adjacent marshes and to create wooded habitats and conduits for sediment-transport conveyance channels.

D Hydraulics and morphology

This appendix is- in our view - roughly 70 percent complete.
Results of additional analysis on hydraulics and morphology will be added to this appendix.
Figures and tables will be improved.
References will be checked and if necessary corrected

Preface

In the framework on the project activities on hydraulics and morphology – in line with the project proposal – only relatively simple methods are used to determine the hydraulic effects (surges, waves) of possible measures and strategies. The detailed method and models developed in the IPET-project and also followed in the LAPCR-project, is not available to the project team. That method follows a full probabilistic approach with detailed hydrodynamic calculations with the ADCIRC-model for a series of hurricanes, each marked by different wind speeds, diameter, track and forward speed. Applying that method in the current project would require an effort that by far exceeds the time available to carry out the project. Instead, the Dutch team applies relatively simple methods aimed at providing sufficient information to reach conclusions at reconnaissance level.

D.1 Mississippi River flows and sediment loads

The Mississippi River discharges the headwater flows from about 41 percent of the contiguous 48 states. On a long-term daily basis, discharges in the Mississippi River average 470,000 cfs. A peak discharge of approximately 1,250,000 cfs occurs on the average of once every 16 years downstream of New Orleans.

Following a disastrous Mississippi flood in 1927, the federal government began building levees in earnest to protect the Mississippi Delta, including New Orleans. Oil and gas development in the region added to the problem as exploration companies built canals across the delta for building drilling platforms and for routing pipelines. Shipping canals for better access to the Port of New Orleans further disrupted the natural processes in the delta. Silt that once replenished the delta, nourishing its oceans of marsh grass, flowed straight into the Gulf of Mexico.

Suspended sediment concentrations in the river decreased markedly between 1950 and 1966. Since that time the observed decrease in the suspended sediment load has been minimal. Long-term suspended sediment loads in the river average 436,000 tons per day; they have ranged from an average of 1,576,000 tons per day in 1951 to a still considerable average of 219,000 tons per day in 1988.

Recent studies by the USACE (Keown et al. 1980) indicate that the suspended sediment load of the Mississippi River has decreased substantially during the last 20 years, especially the larger-grain-sized sediments (sands). Causes of these changes include:

1. the construction of reservoirs in Mississippi River tributaries (especially upper Missouri River tributaries, sources of most of the coarse sediments);
2. improved soil conservation practices (i.e., less topsoil erosion);
3. the mining of pointbar (river) sands for construction and industrial usage; and
4. the dredging and land disposal of riverine sediments. The net effect of this upstream sediment use is to reduce the amount available for deltaic sedimentation, nourishment of barrier beaches, and transport into marshes by floods and tidal currents. The decrease in grain sizes has also reduced the land-building potential.

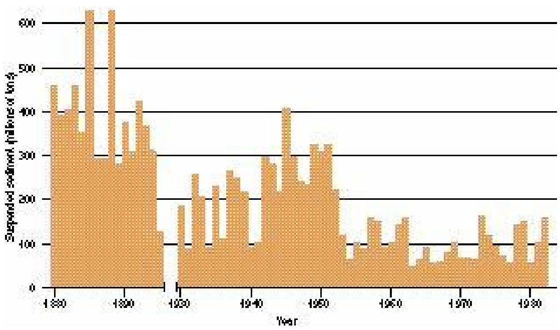


Figure 42 Historical record of the suspended sediment load of the Mississippi River at New Orleans (Kesel 1987). Historical period = before 1900, pre-dam period = 19301952, and post-dam period = 1963-1982. http://biology.usgs.gov/s+t/SNT/noframe/gc138.htm

Sediment budgets

To be detailed

Coastal sediment transport

To be detailed

D.2 Safety of New Orleans for different Delta scenarios

Results presented in this section are based on an un-calibrated model. Furthermore, wind and short wave effects are not accounted for in the present model setup. Results will be updated with more comprehensive model schematizations at a later stage. All results presented here should be interpreted with care and can not directly be used in any construction design or planning effort.

In all simulations the hurricane Katrina characteristics were used.

The effect of vegetation is included in the model, but its effect was not calibrated. Therefore only relative (qualitative) comparisons can be made, quantitative comparisons can not be made.

Introduction

Within this topic two parallel approaches are followed. With a realistic model of the Mississippi Delta a number of scenarios representing different delta configurations (present, pessimistic and optimistic) were investigated to illustrate the role the delta has in the protection of the hinterland. This approach is referred to as the ‘prototype modeling approach’. The other approach, the so-called ‘schematic approach’, is aimed at providing insight into the effect various components of which a delta consist influence the surge levels.

In the following sections set-up and results are discussed for both approaches.

Prototype modeling approach

At this stage of the study two delta configurations and two hurricane paths were investigated. The delta configurations are a delta with vegetation and without vegetation (size of delta was not modified). The original Katrina path was taken and a path which was shifted 0.5 deg Westward, to investigate a possible funnel effect in the Barataria basin.

The effect of vegetation

The maximum surge levels for Katrina are shown in Figure 43. Notice that only tide, wind and pressure effects are included. The effect of locally generated wind waves will result in a significant increase in surge levels. From the plots it is apparent the effects on surge levels in the vicinity of New Orleans is relatively minor. However, at the Birdfoot and in the delta East of the Birdfoot (Breton Sound and Chandelier Sound) some noticeable differences can be observed. West of the Birdfoot the vegetation reduces the water levels near the levees, whereas East of the Birdfoot the vegetation induces a significant water level increase. At the area East of LP (Waveland) the differences are minor.

Hurricane path

Shifting the hurricane path 0.5 deg Westward results in an expected increase in surge levels in the Barataria basin, whereas Eastward of the Birdfoot surge levels have reduced (Figure 44). Now the effect of the vegetation is more pronounced. Although maximum surge levels are higher with the vegetation the intrusion distance has reduced significantly and the surge levels at the levees are reduced by 30 to 50%.

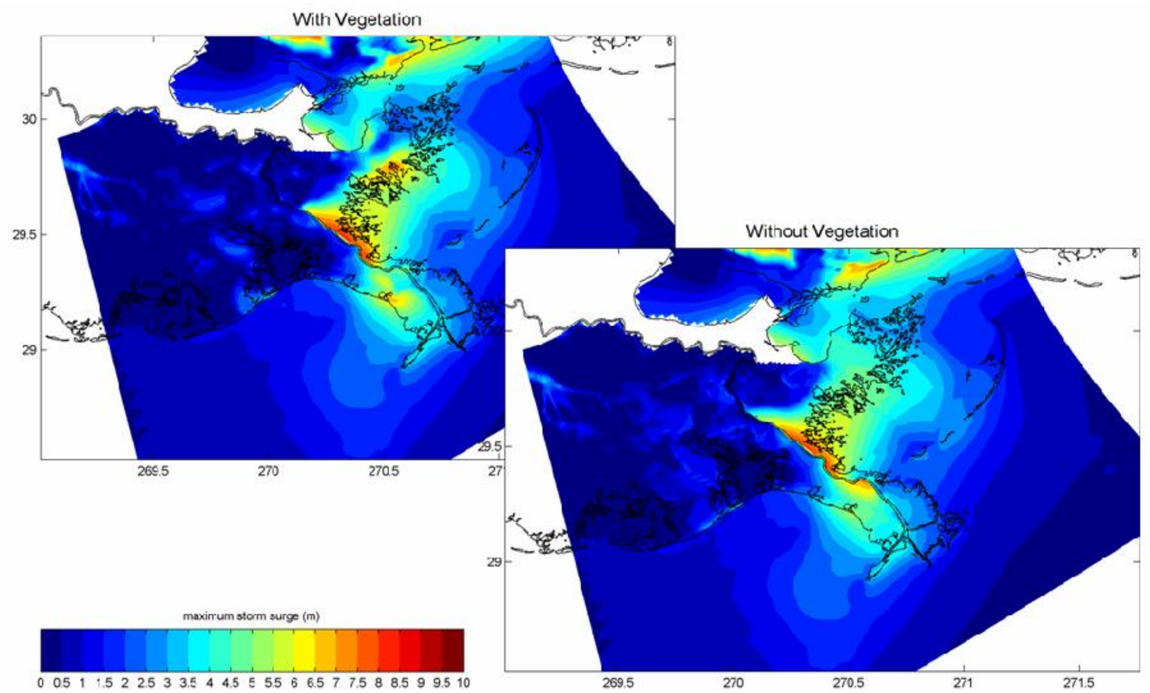


Figure 43 Maximum surge levels for Katrina with and without vegetation (m).

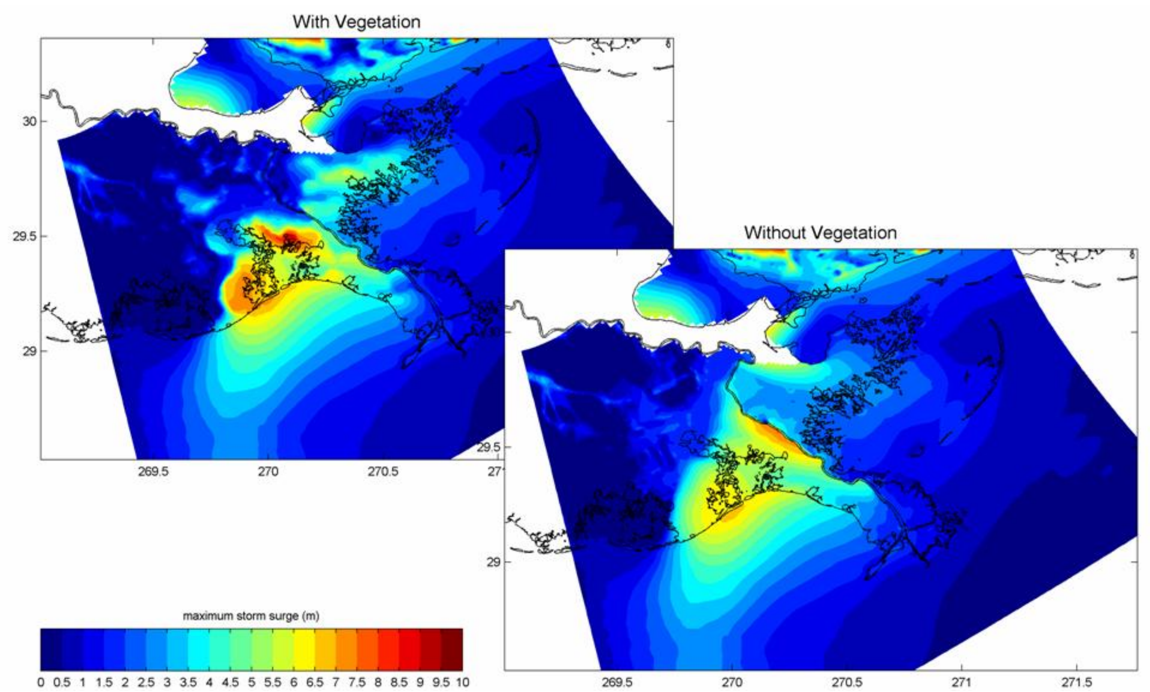


Figure 44 Maximum surge levels for Katrina shifted 0.5 Deg Westward with and without vegetation (m).

Schematic approach

In the schematic approach the storm surge during a hurricane landfall at a straight coast was investigated in a number of simulations. The model domain of the schematic model is shown in Figure 45. Figure 46 shows the cross-shore profile. A large shallow plateau with a width of 50 km and a depth of 1.0 m is situated in front of the coast line. To the South the bottom drops to a maximum depth of 100 m with a slope of approximately 1 in 500. The initial water level in the model was set at 0 m. The imposed hurricane was based on Katrina (wind speeds up to approximately 150 knots) and the hurricane path was from South to North through the center of the domain.

The schematic model is used to qualitatively investigate the effects of: vegetation, funneling and barrier islands.

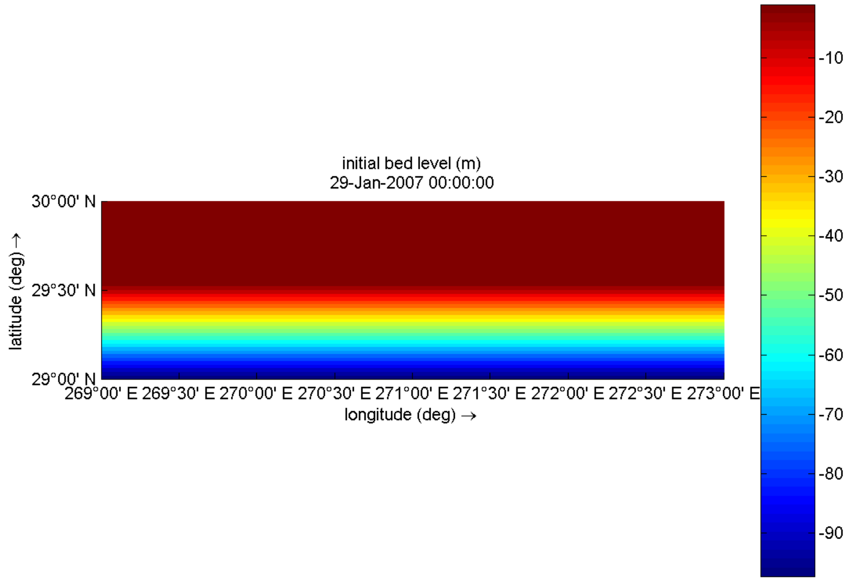


Figure 45 Schematic bathymetry (m).

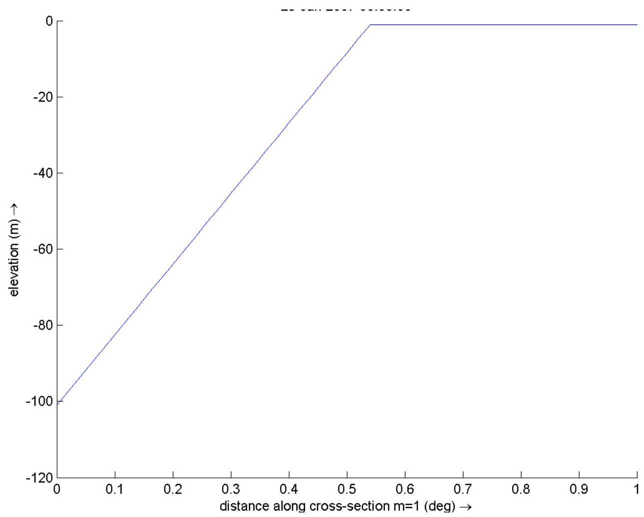


Figure 46 Cross-shore profile.

A set of five Delft3D hydrodynamic simulations have been executed. The maximum surge levels are summarized in Figure 47. The following conclusions are drawn from this investigation:

1. The storm surge in the reference simulation reaches a maximum height of approximately 11 m. This height is similar to the maximum observed storm surge at landfall during Hurricane Katrina.

2. Vegetation (Spartina) has been introduced in the model over the entire shallow plateau. This increases the storm surge just South of the plateau to some extent, but it drastically reduces the storm surge at land fall. A similar effect could be seen in the results of the prototype modeling of Hurricane Katrina (see also Figure 43). The effect however is now much larger. This is most likely due to the fact the vegetation now covers a continuous and much larger area, whereas in the prototype modeling, only grid cells that were situated above mean sea level contained vegetation.

3. A large levee has been inserted in the center of the model in order to create a funnel effect during hurricane landfall. Figure 47 shows that this effect has the potential to increase surge levels significantly. In this case, the surge levels are increased with approximately 20 percent. The extent of the funnel effect probably depends also on the angle of incidence of the hurricane path with the coast line.

In two of the simulations, a row of barrier islands at the edge of the shallow plateau has been included in the model schematization. The barrier islands are each 12 km long with 8 km wide gaps in between them. In the first simulation, the height of the islands was set at +3 m MSL, whereas in the second, the height was set at +10 m MSL. The aim of this distinction was to investigate whether overwashing of the islands (which can only occur in the first simulation with relatively low barrier islands) adds to the maximum storm surge levels. The barrier islands appear to cause a lowering of about 1 m of the maximum storm surge at land fall. Overwashing of the islands does not seem to affect water levels at landfall, but it does cause a significant increase of storm surge levels just landward of the barrier islands.

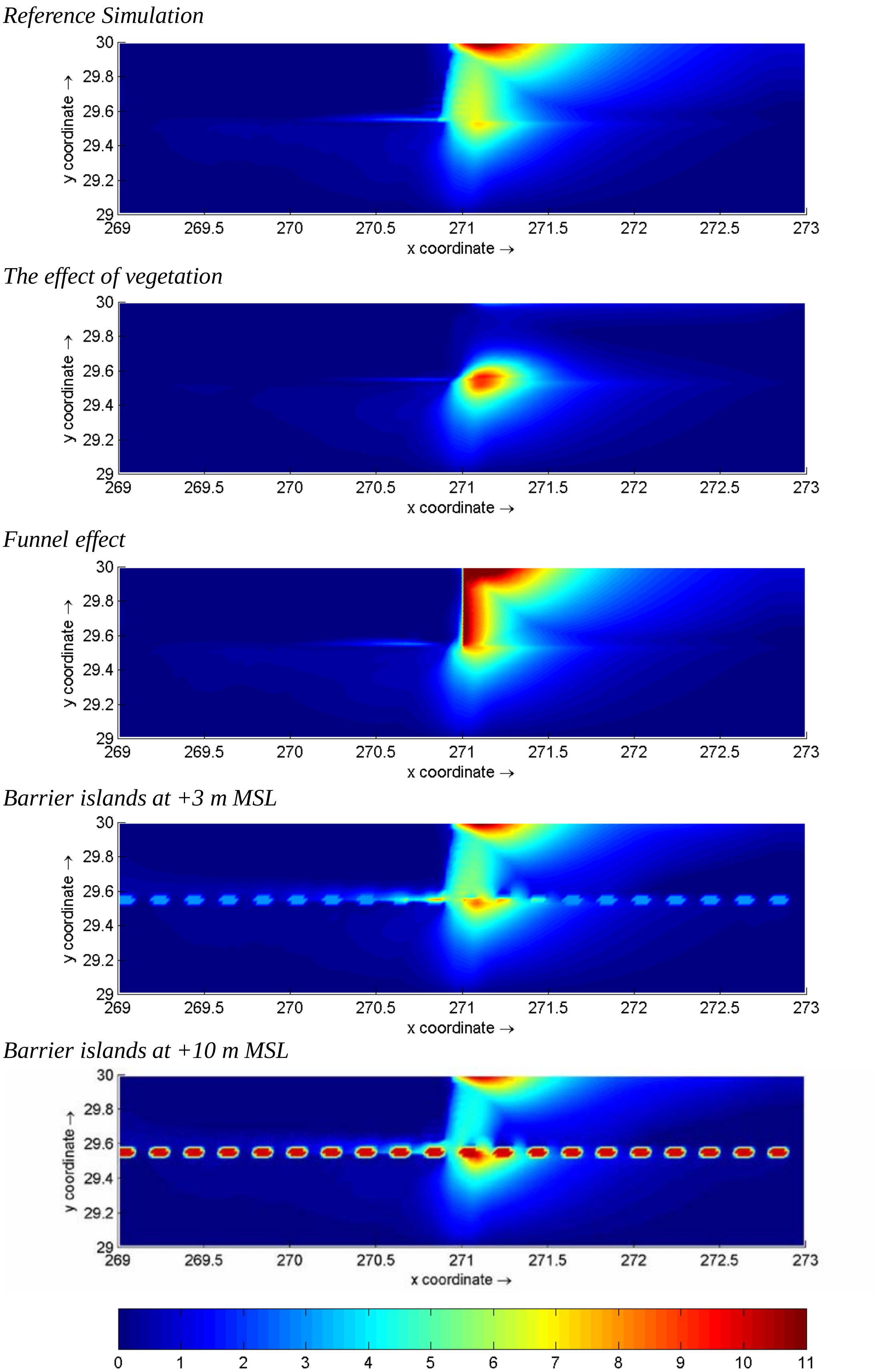


Figure 47 Maximum water levels (m) for various schematic delta configurations

D.3 Modeling sediment transport

Preliminary Delft3D simulations have been carried out in which sediment fluxes and salinity levels have been determined for the present situation as well as for a number of future scenarios. The aim of this exercise was to investigate the effects of a number of proposed interventions, such as the creation of diversion channels just South of the Plaquemines and top get a feeling for the sediment dynamics in the area. The simulations were carried out on the same model grid as the storm surge simulations (see section D.4).

The river discharge was chosen at 20,000 m^3/s with a sediment concentration of 0.25 g/l. This yields a yearly sediment load of 200 million tons of sediment which is in agreement with recently observed sediment loads from the Mississippi River. In these preliminary simulations, only the fine (cohesive) sediment fraction has been taken into account. Wind and wave action have not been included at this stage. The deposition of river sediment has been investigated for the following scenarios:

- Present situation (over a period of 10 years)
- Narrow (1 km) and deep (15 m) diversion channels South of Plaquemines (over a period of 10 years)
- Wide (5 km) and shallow (5 m) diversion (over a period of 2 years)

The simulations are run over a period of one month (two spring-neap cycles). The use of a morphological acceleration factor allows the scaling of bed level changes (deposition of river sediment) to a longer period. In the first two simulations, this factor was set to 120, which yielded a total morphological time of 120 months (10 years). In the third simulation, the factor was set to 24. The initial salinity is set to 31 ppt throughout the entire model domain.

Present situation

Figure 48 shows the thickness of the deposited river sediment after 10 years for the present situation. It appears that most of the sediment settles relatively close to the river mouth, thereby contributing to the continuous expansion of the Birdfoot. This can be explained by the fact that tidal currents are small in this area and can therefore not transport the river sediments over large distances. It must be noted again that wind and waves were not taken into account. In reality, wind-driven currents and additional wave stirring will spread the sediment plume over a larger area.

Figure 49 shows the computed salinity at the end of the simulation (i.e. after one month). The higher density of the sea water ensures that the fresh water plume is pushed against the delta. This does not seem entirely realistic. In reality, it can be expected some vertical stratification will occur. In that case the fresh water plume will not so much be pushed against the delta by the denser sea water, but will instead flow (to some extent) over the more saline water from the Gulf (forming a ‘bubble’ of fresh water on top of the salt water). This effect has not been taken into account in these preliminary depth-averaged simulations. It should therefore be investigated further in the future by also carrying out a number of 3D simulations. Furthermore, wind driven currents and waves will probably further spread out the fresh water plume.

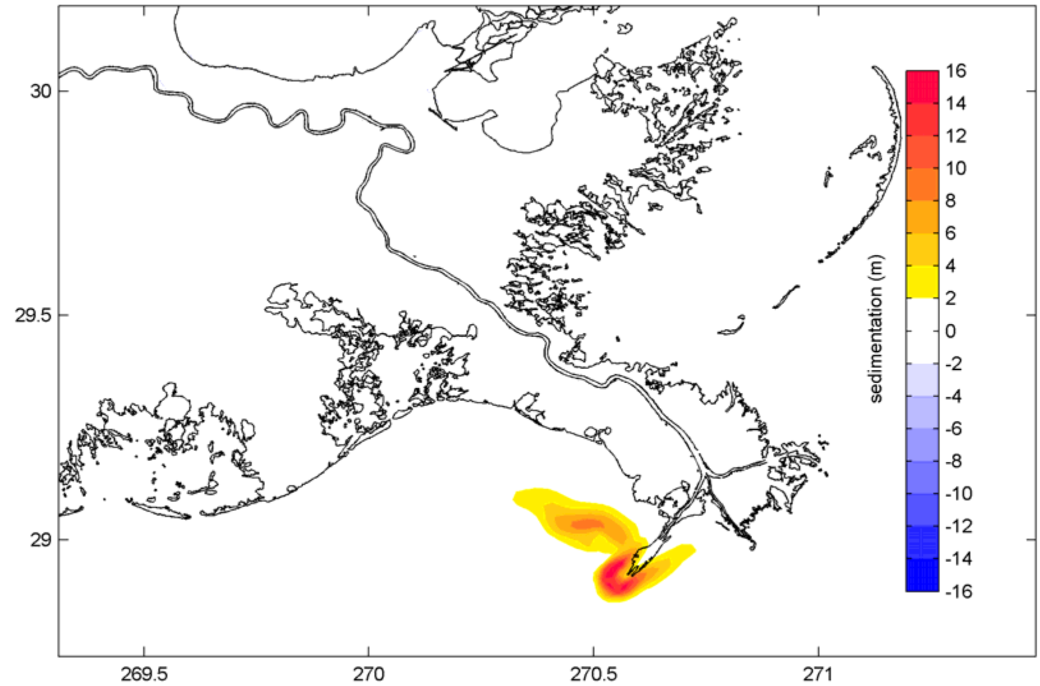


Figure 48 Deposition of river sediments over 10 year in the present situation (m)

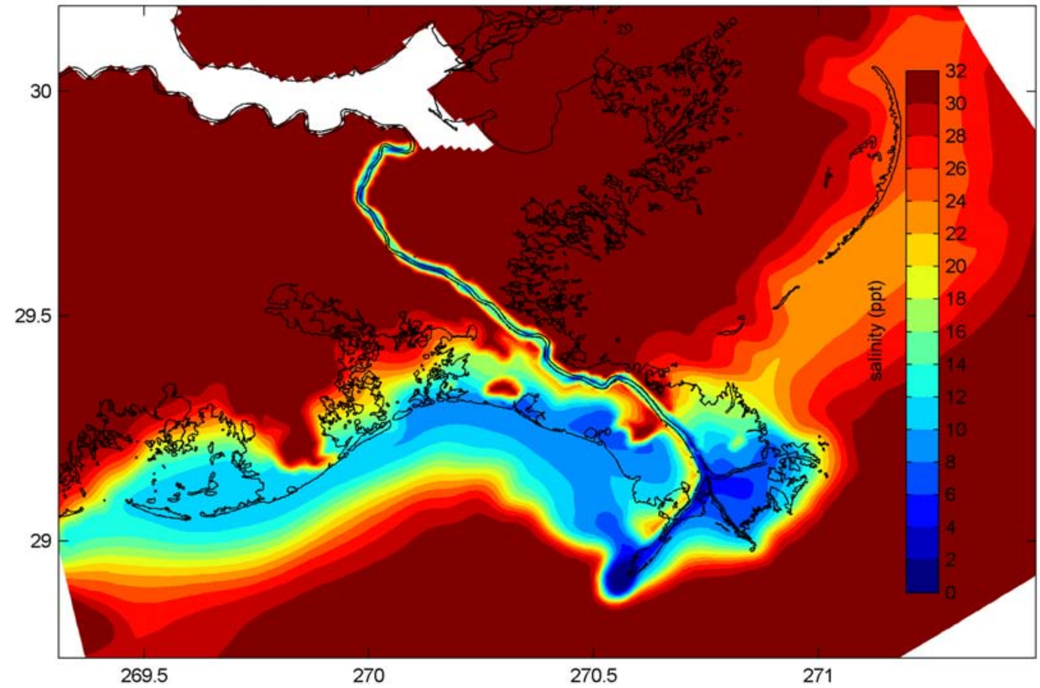


Figure 49 Salinity after one month in the present situation (ppt)

Narrow diversion channels

Figure 50 shows the bathymetry for the scenario in which two relatively narrow (approx. 1 km) and deep (15 m) diversion channels have been dredged.

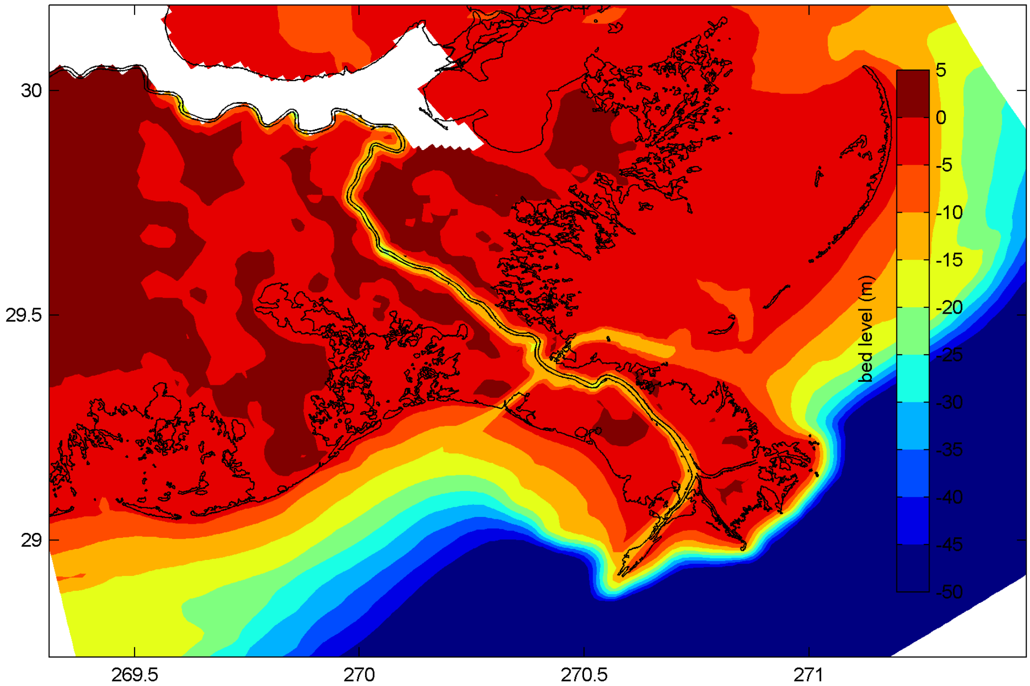


Figure 50 Bathymetry with narrow diversion channels (m)

Strong deposition occurs in the newly dredged channels (see Figure 51), but most of the river sediments are deposited along the banks of the Western diversion channel. It appears that a new branch to the Birdfoot, similar to the Atchafalaya Delta will be formed after the creation of the diversion channels. Strong deposition also occurs in the original navigation channel downstream of the diversion channels. This is caused by the fact that current velocities have been reduced significantly here, as approx. 80 percent of the river discharge now enters the Gulf of Mexico through the diversion channels.

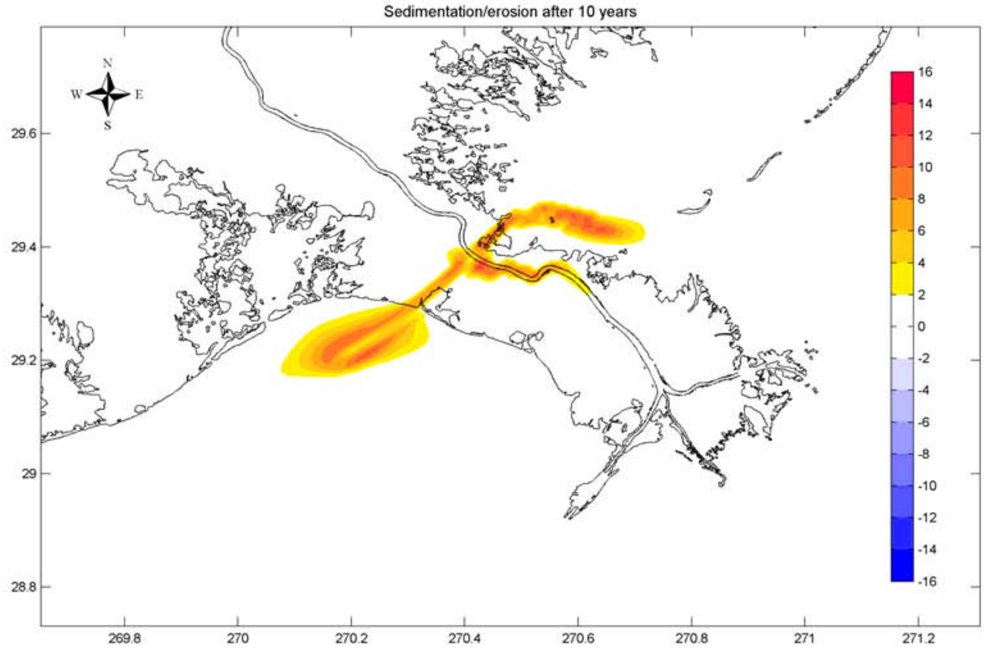


Figure 51 Deposition of river sediments over 10 year with narrow diversion channels (m)

Figure 52 shows the salinity after one month. It appears that the dredging of the two diversion channels caused a large drop of salinity levels in the Delta. It must however be stated that 3D effects and wind-driven currents must probably be taken into account in order to properly model this phenomenon.

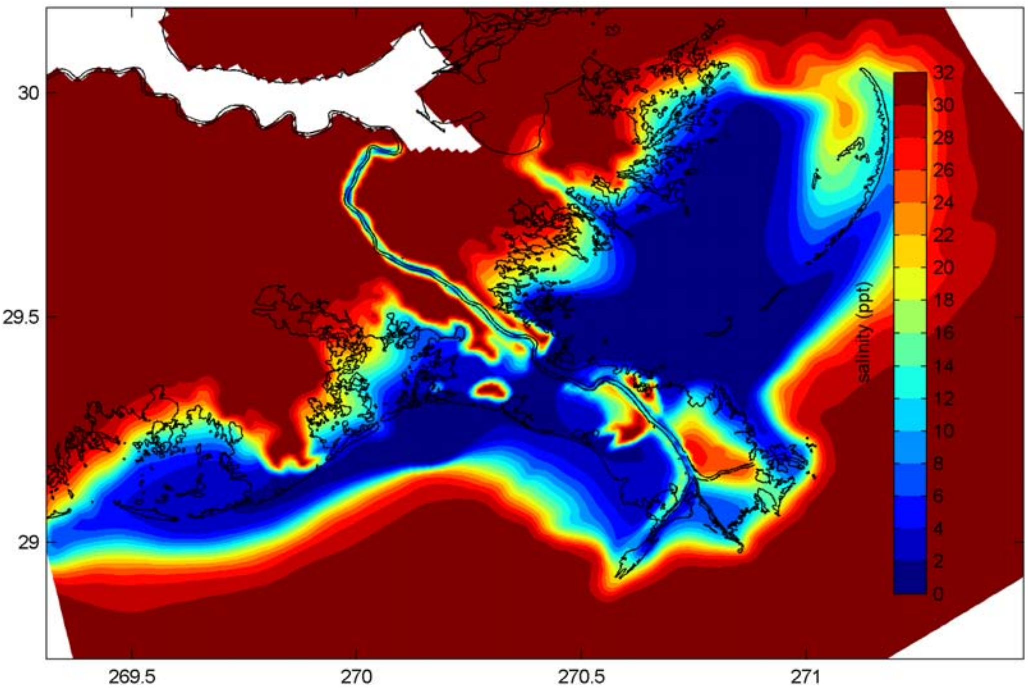


Figure 52 Salinity after one month with narrow diversion channels (ppt)

Wide diversion channels

Figure 53 shows the bathymetry for the scenario in which two wide (5 km) and shallow (5 m) diversion channels have been dredged.

Figure 54 shows the deposition of river sediments after 2 years. The pattern looks somewhat similar to Figure 51 but the sediment load appears to be deposited closer to the Birdfoot. This is caused by the fact that the current velocities in this scenario are lower than in the scenario with two deep and narrow diversion channels. The underlying reason to study this scenario was to see whether 'disconnecting' the Birdfoot would lead to a strong tidal current through the newly dredged channel. It was thought that this current could redistribute sediment in the longshore direction, thereby effectively 'nourishing' the delta. However, it appears that there is no significant tidal longshore current. Furthermore, the total volume of sediment that would need to be dredged from the wide channel is so large that this alternative is probably not realistic.

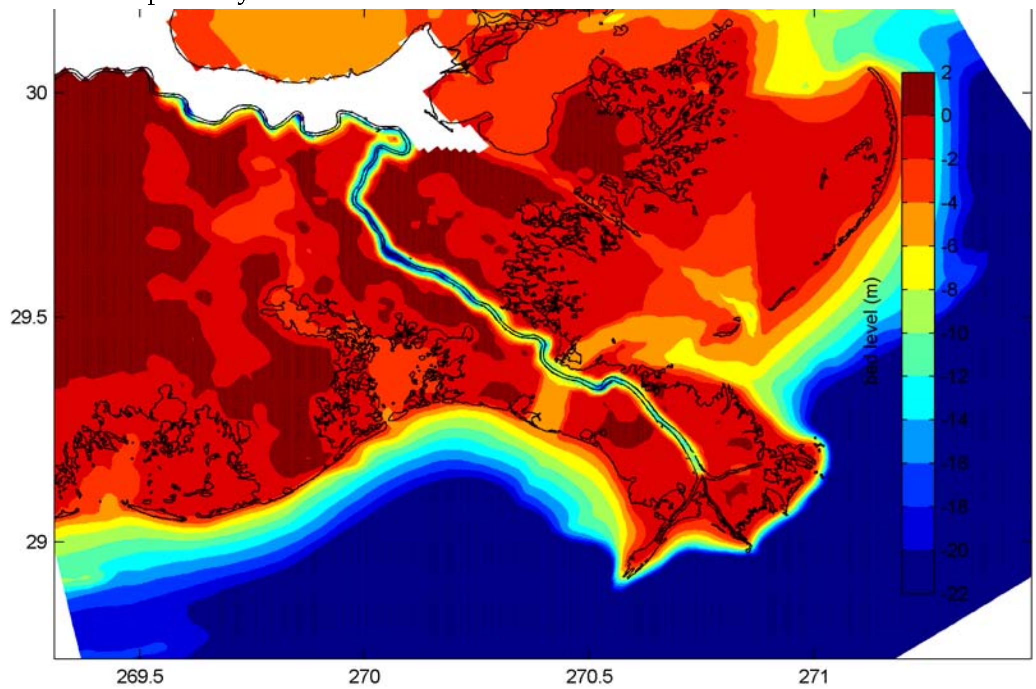


Figure 53 Bathymetry with wide and shallow diversion channels (m)

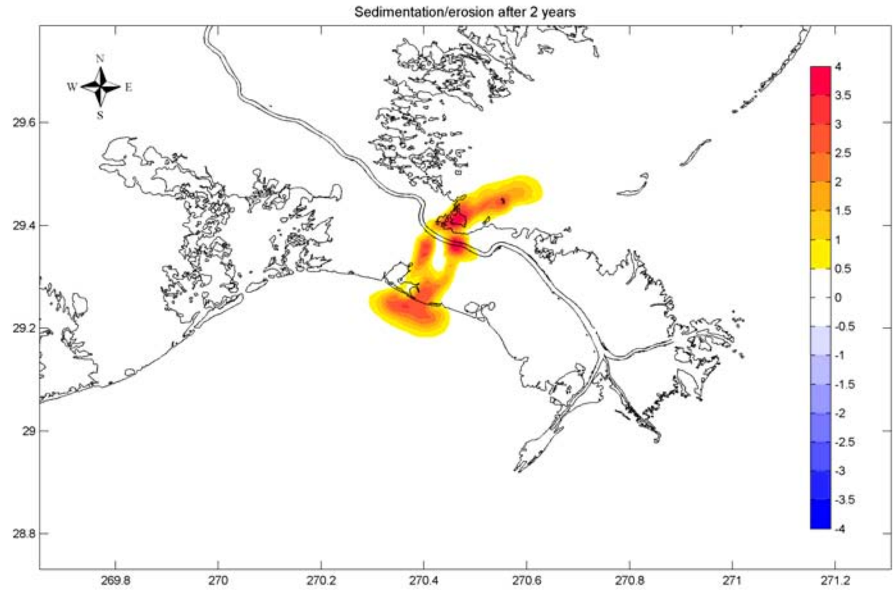


Figure 54 Deposition of river sediments over 2 year in the present situation (m)

Conclusions

Creating diversion channels will have a large impact on sediment dynamics and salinity distribution in the Mississippi Delta. It appears that new lobes will be formed on the Birdfoot at the downstream reaches of the diversion channels. Most of the freshwater discharge will flow into the Gulf through the diversion channels. Current velocities in the original shipping channel will therefore drop significantly with strong siltation as a result.
It should be noted that the relatively narrow diversion channels are still 1 km wide. This is the smallest possible width that can be resolved with the present computational grid.

The following actions should be undertaken before recommencing the modeling activities:

- Calibration and validation of the hurricane wind field (spiderweb)
- Schematization of representative tide, wind and waves
- Extend model with correct levee heights and locations
- Determination of discharge scenarios for computations of salinity gradients
- Improving schematization of sediment load (grain diameter, settling velocity)

D.4 Modeling

The Delft3D model grid consists of a curvilinear grid with approximately 23,000 active grid cells. The bathymetry for the model has been obtained by interpolating the bathymetric data from a detailed ADCIRC model onto the computational grid. Figure 55 shows the model bathymetry.

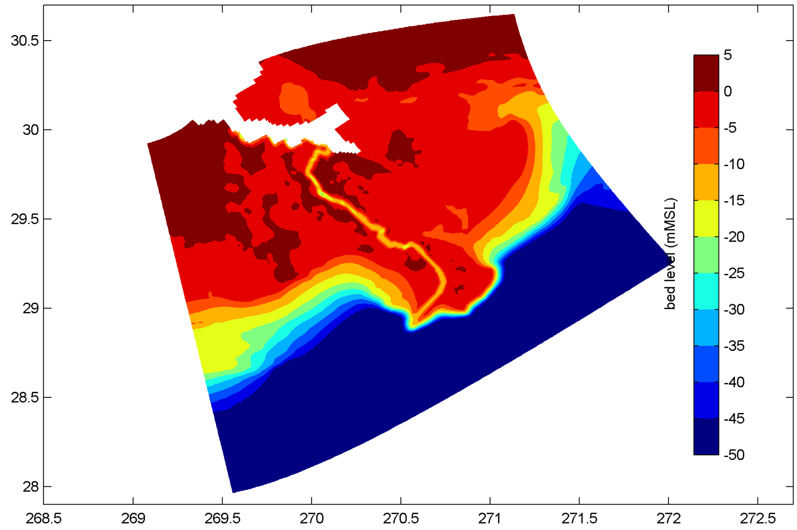


Figure 55 Model bathymetry (m)

Figure 56 shows the computational grid itself. The horizontal grid spacing varies from 500 m to 2 km.

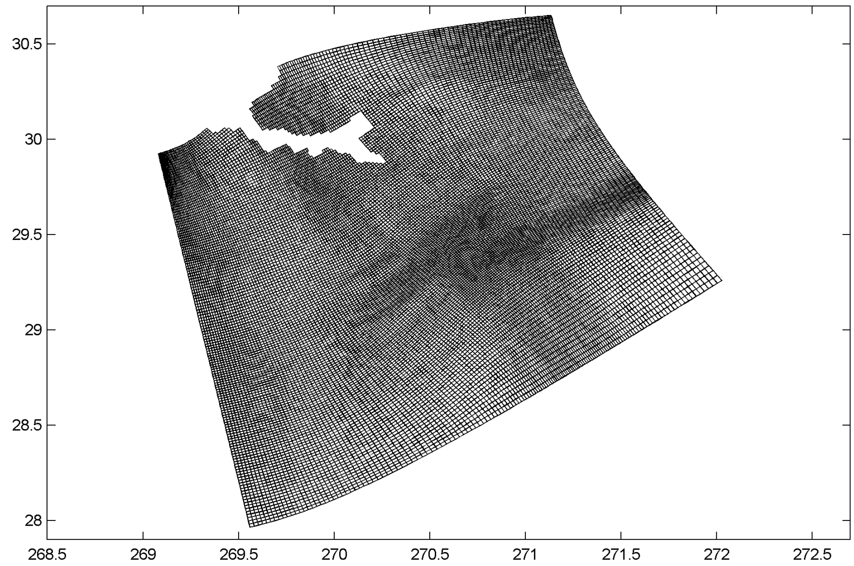


Figure 56 Model grid

Boundary conditions

Boundary conditions for the detailed model have been generated with an overall model of the Gulf of Mexico. The bathymetric data for this model has been obtained from the ETOPO5 data set. The overall model has a horizontal grid spacing of approximately 20 km (Figure 57). The same figure also shows the computational grid of the detailed model in red. The GOM model has been successfully calibrated to predict water levels in the vicinity of the Mississippi Delta. Figure 58 shows a time series of water levels at South Pass (at the Southern tip of the *Birdfoot*). The blue line shows the computed water levels whereas the red line represents the water level prediction based on astronomical components.

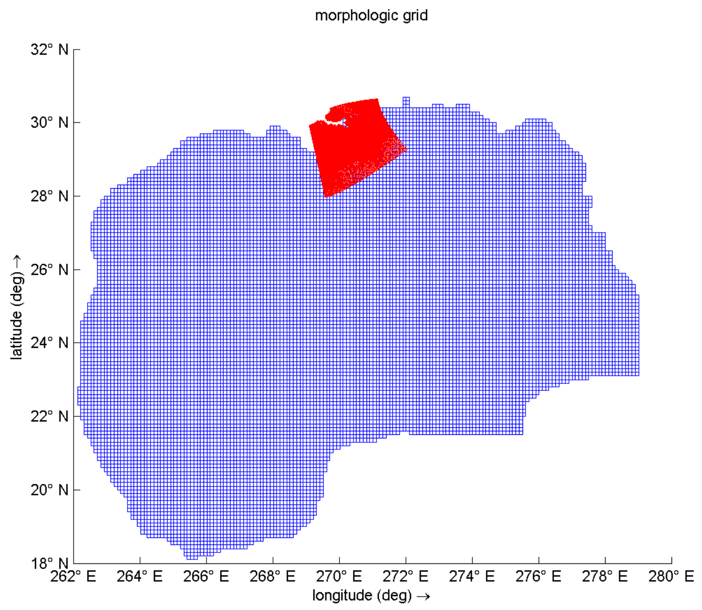


Figure 57 Computational grid of Gulf of Mexico model

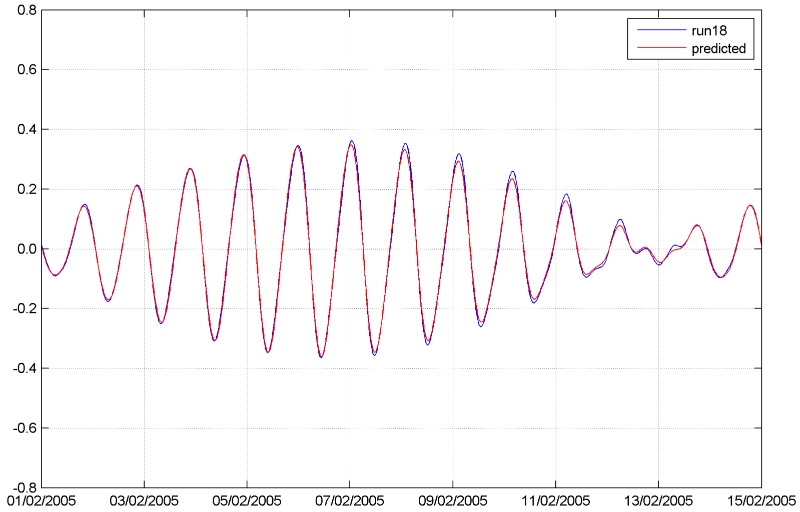


Figure 58 Computed (blue) and predicted (red) water levels at South Pass

An automatic nesting procedure has been used to derive boundary conditions for the detailed model from the GOM model.

Hurricane (incl Spiderweb)

A spatially and time varying wind field has been applied in order to include Hurricane Katrina in the model. The track of the hurricane, the maximum pressure drop and the maximum wind speed are well described by this wind field, but there are some uncertainties about the radius of maximum wind speed. A further validation of the wind field is required by comparing with data from meteorological observations in the area.

Validation

The model validation has been postponed until the software problems in SWAN have been resolved (which by now is the case). (Figure water levels Pilot Station East)

E Values to be protected and optimal flood protection levels

This appendix is- in our view - roughly 50 percent complete.
Input data – most likely especially regarding construction costs – will be improved pending cost estimates that still have to be drafted
An important condition for this work to be completed is the availability of IPET Volume VIII on flooding risks.
Figures and tables will be improved.
References will be checked and if necessary corrected

E.1 Values to be protected

To be detailed.
(IPET Volume VIII) is important here, but not yet available….

E.2 Optimal flood protection level for New Orleans

Introduction

This section focuses on the optimal safety level for New Orleans. Objectives are the following:

- To give an example of the risk-based approach as will be used in the Dutch Deltaplan.
- To give insight in the order of magnitude of optimal flood protection for the Orleans bowl
- To identify the information required to carry out such an analysis and to show the sensitivity of the outcomes for the input values
- To identify the links with other parts of the Dutch Deltaplan project and the pieces of information that will have to be exchanged.

Approach and assumptions:

- Apply the economic optimization method originally proposed by Delta the Committee (van Dantzig, 1956)
- Investigate the order of magnitude of the optimal protection level by considering various predefined safety levels: 1/10; 1/100; 1/1000; 1/10,000; 1/100,000 per year.
- Use design water levels that correspond to the above mentioned protection levels. The assumed levee height is based on the design water level. The effects of wave run-up have to be addressed later.
- As a measure only levee strengthening is considered at this stage. The effects of other measures (e.g. damage reduction) can be considered in the same conceptual manner.
- This first analysis focuses on the Central part of the city of New Orleans, the so-called Orleans bowl (see Figure 60).

- Indicative, but realistic estimates will be used for input data for costs and flood damages. In later investigations the input data has to be refined and based on available data.
- The emphasis is on hurricane surge protection. The risks of river flooding are not considered. For an integrated risk-based approach these will have to be combined.

E.3 Approach and input information

Approach: economic optimization

The economic optimization method (Figure 59) as proposed by the Delta Committee (van Dantzig, 1956) will be used in this analysis. It has been developed in the Netherlands after the 1953 storm surge to decide on an acceptable level of flood protection. In an econometric analysis the optimal safety level was determined for the largest flood prone area, South Holland. In this optimization approach, the incremental investments in more safety are balanced with the reduction of the risk.

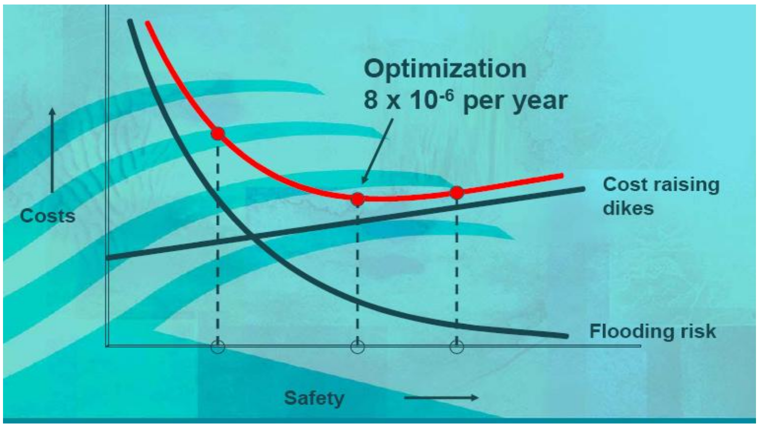


Figure 59 Economic optimization (1956) for optimal flood protection level for coastal areas in the Netherlands.

Study area

Focus area is the central part of Orleans, the so-called Orleans bowl, area number 1 in Figure 60. It is bounded by the Lake Pontchartrain in the North, the Industrial Canal in the East, the Mississippi river in the South, and in the West by some higher grounds and the 17th Street Canal levees. This areas has more than 300,000 inhabitants and it includes the cultural heart of New Orleans, the French Quarter.

Figure 60 New Orleans: situation and the distinguished bowls: 1 – Orleans; 2 – Orleans East; 3 – St. Bernard.

Input information

To carry out the economic optimization the following information has been used:

- Damage caused by flooding of the Orleans bowl: \$ 20 10^9 (estimate based on Kok *et al.*, 2006)

Investment costs in levee strengthening:

- Length of flood defenses: 15 km (7,5 km along lake Pontchartrain and 7,5 km along the Industrial Canal)
- Investments costs per km will differ between the Lake Pontchartrain levees and the Industrial Canal levees. The Lake Pontchartrain levees are earthen levees and can be heightened and strengthened relatively easily. The levees along the Industrial Canal consist of (concrete) floodwalls. Strengthening will be more costly. The costs of levee strengthening consist of two types of costs: fixed (or mobilization) costs and a variable costs factor that is dependent on the amount of heightening. Based on best estimates the following investment costs per kilometer levee are assumed:
  - Along lake Pontchartrain: \$ 2 $10^6 + 10^6\ \Delta h$
  - Along the Industrial Canal: \$ 3 $10^6 + 10^6\ \Delta h$
  - Where: Δh = amount of levee heightening [m]

Safety levels:

- The current flooding probability of the Orleans bowl is: 1/50 year
- The corresponding design water level is assumed to equal 4 m.
- To reduce the flooding probability by a factor 10, a levee heightening of 1 m is needed, see Figure 61. (in Dutch this relationship is indicated as the '*Decimeringshoogte*', mistakenly translated in this figure as '*decimation height*'). This implies that there is a linear relationship between design water level (levee height) and the logarithm of the return period.
- The Discount rate minus economic growth equals 2.5%

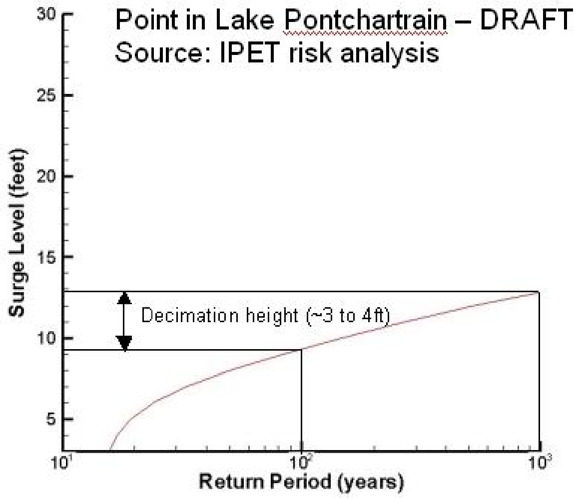


Figure 61 Lake Pontchartrain: relationship between return period and surge level.

The presented data are best (but realistic) estimates by the authors. The input data has to be verified and specified further based on actual information from USACE and other sources. The sensitivity of the outcome (i.e. the optimal level of protection) will be investigated for different values of the above parameters.

E.4 Results of economic optimization

Base case

The outcomes for the base case are presented in Table 4 and Figure 62. Both the table and the figure show the same information but in different format. The optimal level of flood protection that follows from the analysis is 1/100,000 years (indicated in bold in the table). Such a relatively high level of protection is found, because the damage in case of flooding is very large and the safety can be improved at relatively low cost. Sensitivity analyses are presented in the next section.

Table 4 Economic optimization for Orleans: Input information and results

Return period (yr)	50	100	1,000	10,000	**100,000**	1,000,000
Flooding probability (yr^{-1})	2.0E-02	1.0E-02	1.0E-03	1.0E-04	**1.0E-05**	1.0E-06
Design water level (m)	4.0	4.3	5.3	6.3	**7.3**	8.3
Investments ($)	3.75E+07	4.20E+07	5.70E+07	7.20E+07	**8.70E+07**	1.02E+08
Risk ($)	1.60E+10	8.00E+09	8.00E+08	8.00E+07	**8.00E+06**	8.00E+05
Total Costs ($)	1.60E+10	8.04E+09	8.57E+08	1.52E+08	**9.50E+07**	1.03E+08

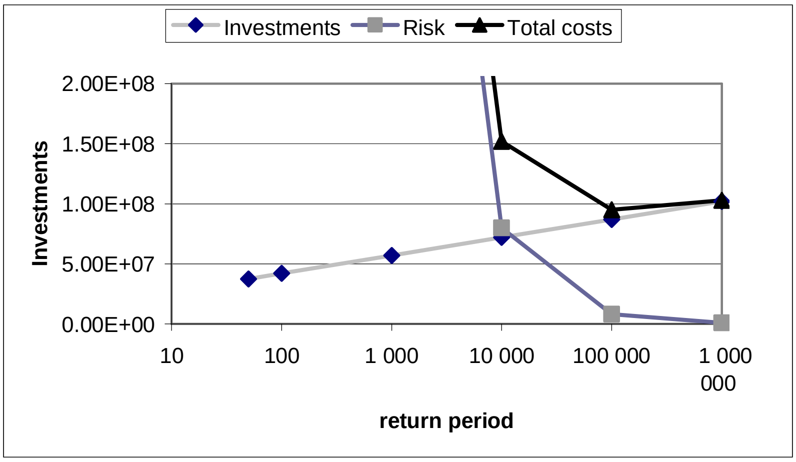


Figure 62 Results of economic optimization for the Orleans bowl

Sensitivity analyses

Below the sensitivity of the outcomes of the obtained optimum is investigated for some parameters, i.e. the flood damage value, investment costs, and current safety level.

Damage value

In the base case a flood damage value of 20 billion US$ has been assumed. The economic optimum for two other values, namely 10 billion US$ and 50 billion US$. The results are shown in Figure 63. This shows that an increase of the damage could lead to an even higher optimal protection level.

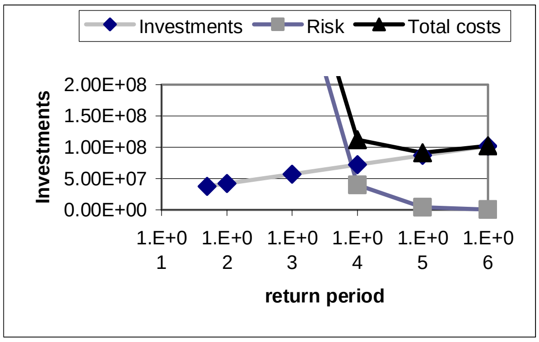
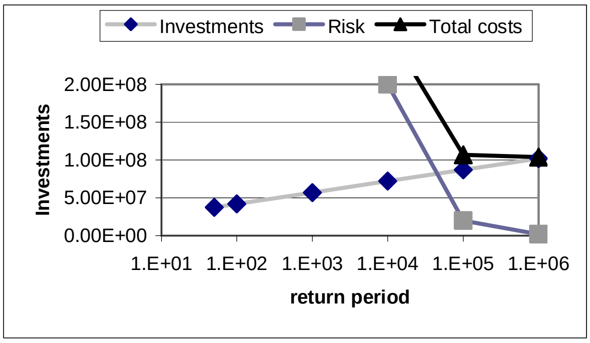
Damage = 10 billion US$ Optimum: 1/100,000 years	Damage = 50 billion US$ Optimum: 1/1,000,000 years
	

Figure 63 Sensitivity of economic optimum for the damage value

Investment costs

The influence of investment costs on the optimum has been investigated (Figure 64). Firstly, the influence of double investment costs has been investigated (both for fixed and variable costs). This leads to an increase of the total cost, but does not change the optimum.

Secondly, in the base case a linear relationship between return period and levee height has been assumed. Thereby the investment cost is linearly dependent on the return period. For sensitivity analyses a non-linear relationship is assumed. To illustrate the sensitivity for an extreme case a quadratic relationship between investment cost and return period is assumed (i.e. the relationship between investment and levee heightening becomes quadratic). This leads to an optimum of 1/10,000 years. However, it has to be noted that the total cost values for 1/10,000 and 1/100,000 protection are nearly the same (see Figure 64).

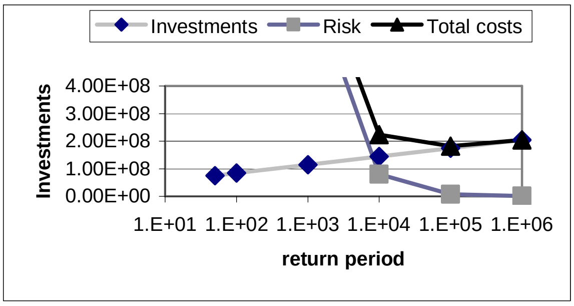
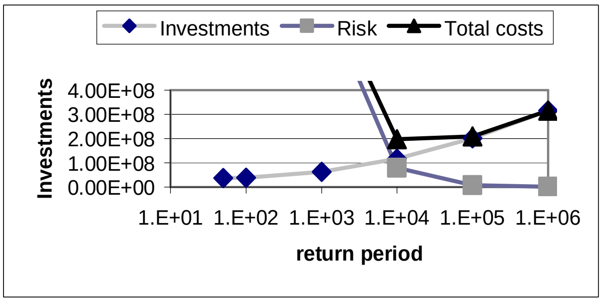
Double investment cost Optimum: 1/100,000	Quadratic investment cost Optimum: 1/10,000
	

Figure 64 Sensitivity of economic optimum for different investment costs

Safety levels and relationship with hydraulic design water levels

Firstly, in the base case a current safety level of 1/50 years has been assumed. This might be too conservative and for sensitivity analysis it has been assumed that the initial safety level is 1/200 years. This leads to the fact that it becomes (relatively) cheaper to reach a higher safety level. However, this does not influence the optimal protection level, which remains 1/100,000.

Secondly, in the previous analyses a decimation height of 1m has been assumed. This is the increase of the design water level (and levee height) that is associated with a reduction of a factor 10 in the exceedance probability. If the decimation height changes to 1,5m the optimum remains 1/100,000 years.

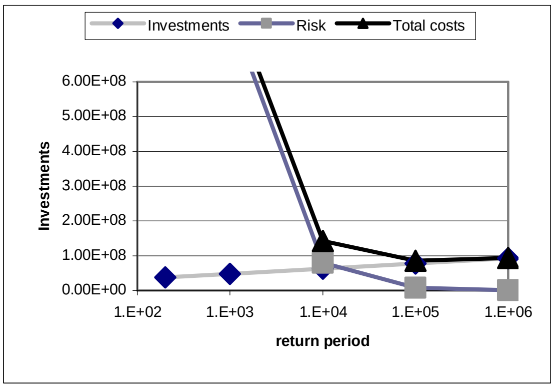
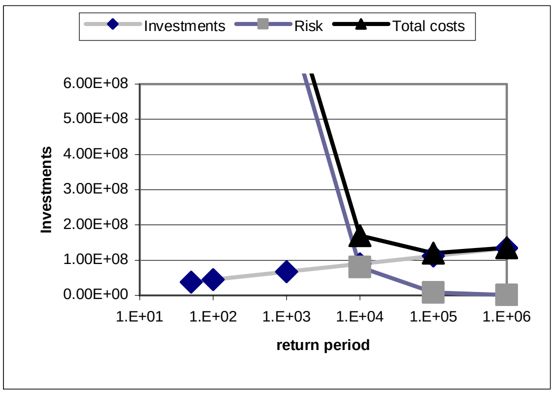
Initial safety level: 1/200 Optimum: 1/100,000	Decimation height: 1.5m Optimum: 1/100,000
	

Figure 65 Sensitivity of economic optimum for initial safety level and decimation height

E.5 Concluding remarks

This section focuses on a preliminary economic optimization for the Orleans bowl. Indicative, but realistic estimates for input data were used. The following has been found:

- The optimal protection level for the Orleans bowl is in the order of 1/100,000 years. Such a relatively high level of protection is found, because the damage in case of flooding is very large and the current safety can be improved at relatively low cost.
- The outcomes are not very sensitive for changes in damage, the investments and assumptions with respect to safety. The assumed relationship between the protection level and the investment increasing cost for higher protection levels has some influence on the obtained optimum.
- Although preliminary and not yet fully realistic the presented outcomes indicate that it is possible to determine the optimal level of safety for the different levee rings / protected areas in SE Louisiana.

The preliminary investigation revealed important links with other parts of the project:

- Hydraulic modeling: design water levels and associated frequencies. Reduction of storm surge conditions for wetlands.
- Measures group: investment costs for different protection level. The actual levee design based on hydraulic design conditions (incl. wave effects) has to be considered.
- Criteria for decision-making. Safety and costs are important aspects.

In later investigations the input data has to be refined and based on available data.
However, given the results of the sensitivity analysis, the outcomes are not expected to change drastically.

Other issues to consider are:

- It would be very useful to obtain the results of the IPET risk analysis. This will give important insight in frequencies of hydraulic design conditions.
- The influence of river floods on the safety of the Orleans levee ring has been neglected. For a full consideration of the safety of the bowl, river floods and investments in improvement of river flood protection have to be considered as well.
- Some measures, such as storm surge barriers and wetlands, will have impacts on more than one levee ring in the system. An approach will be developed to assess the (cost) effectiveness of these types of system measures. For example, for a storm surge barrier a good way of thinking seems to be the following. The costs of the storm surge barrier will be compared with the investments costs in levee strengthening that would be needed to reach the same level of safety. Only if the storm surge barrier brings the same safety at lower cost than the levee strengthening it would be considered effective. It is noted that this example only refers to cost effectiveness. Other aspects, e.g. environmental quality, will be important in making decisions regarding measures.

F Soft soil engineering and structures

This appendix is- in our view - roughly 80 percent complete.
Figures and tables will be improved.
References will be checked and if necessary corrected

F.1 Soft soil engineering

Introduction

For the improvement of the protection of New Orleans against hurricane surges, new levees on soft soils have to be built. Dutch design principles differ from what in many other parts of the world is common practice.

Failure of a levee differs from failure of a concrete or steel structure. In soil mechanics failure usually means shearing. The shear stress depends on the stress between the soil particles. In the situation with soil saturated with water according to Archimedes and his ‘Eureka’ this stress, the so called effective stress, is total stress minus the pore pressure.

$$\sigma' = \sigma - u$$

with:

σ' = effective stress
σ = total stress
u = pore pressure

The Mohr Coulomb model is used to calculate shear resistances.
The resistance against sliding highly depends on the effective stress.

$$\tau = c' + \sigma' tg\varphi'$$

with

τ = shear stress
c’= drained cohesion
ϕ' = friction angle

This means that reducing the value of u makes sense.

In many other countries, calculations are based upon

$$\tau = c_u$$

with

c_u = undrained cohesion

Considering the shear stress this way, lowering the value of u doesn’t change the value of τ.

Improving soil properties by mixing in place with grout or cement is one way; improving the shear stresses by reducing the pore pressures is another way to increase the shear stresses.

Upper layers in Holland consist of Holocene peat and clay, impermeable and compressible. Loading on such layers leads to an immediate rise in pore pressures. Effective stresses, and shear resistance as well, increase only slowly. However, this process can be accelerated.

In this section Dutch design principles will be applied for New Orleans soils.

Data

Location

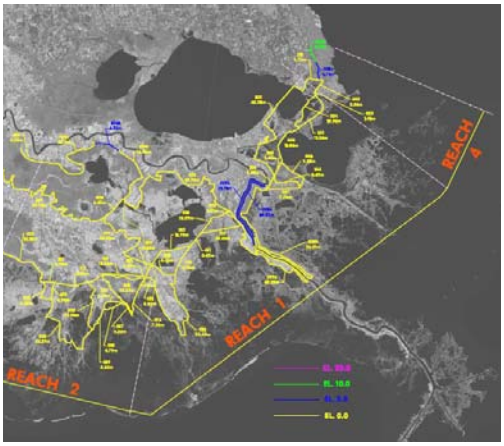


Figure 66 Locations of Reach 1 and Reach 4 for differentiation in soil parameters

For reaches shown in Figure 66 areas, the LACPR-project has made calculations, as shown in enclosure F of LACPR report Engineering Investigations page 187. An alternative calculation, based upon the Dutch view, is described in the following.

Soil

Available materials in the New Orleans area:

- Generally silty. Silt is deposited in areas with little water movement. Typical properties silt: little cohesion. If used without drying with this material only very gentle slopes can be made.
- Local sand ridges at surface. Sandy areas are often in use (built-up areas), so not apt to explore. Typical properties sand: no cohesion but good friction angle.
- Deep sand is generally fine, not coarse sand as usual in the Netherlands, and covered with silty material.
- Locally more coarse sand layers, generally thin and hence relatively expensive not economically to explore.
- Clay: good cohesion. Good clay available, but for exploring to be scraped from big areas. Due to high water content and low liquid limit necessary to dry before use.

Consequences
- Limited quantities of sand, coarse sand even less than fine sand.
- Good clay available, but not easy to get.
- Bulk is inferior material.
- Materials to be used in levees have not ideal properties.

More information about the soil here
- http://ees.uno.edu/kulp/GCAGST_2002_topstratum_manuscript.pdf;
- Technical Report V Appendix 2 page 42 gives geotechnical profiles.

More information about the soil properties
- Technical Report V Appendix 2 page 35 gives different properties, including drained cohesion and drained shear strength;
- Mc Clelland gives in Proc. of the Internat Res Conf Geotechnique 1966 compression indexes;
- In the above mentioned report also measured excess pore pressures are given.

Choices to be made

slopes
- If very gentle slopes are chosen, they can be made so that waves will not break. Material loss can be accepted as long as the core of the levee remains.
- Or if steeper slopes are chosen, the surface has to be protected against breaking waves.

height
- a high levee without overtopping can be chosen;
- or a lower levee with overtopping, this is also possible, but it means that the crest has to be protected.

type
- a choice has to be made between strengthening existing levees;
- or building complete new levees.

existing surface
- levees can be built upon existing land;
- or in water.

Calculations carried out

Settlement
To have some idea about the size of settlements 2 calculations were made for conditions as found by Mc Clelland, borehole 1 (marshland or shallow water, Birdfoot), because for this borehole the necessary soil parameters were available.

1. the first calculation has been made without any external load, only dissipation of measured excess spore pressure have been taken into account. Only the compression index C_c was known, that means only consolidation has been considered, no creep. Time

for consolidation was unknown (no consolidation coefficients were given). Expected consolidation times are long (measured pore pressures give an indication of slow consolidation). The calculated long term settlement is 1,5 m (5 ft).

2. the second calculation has been made with load (gross) 10 m (32 ft) sand, gentle slopes 1 : 30 (outside) and 1 : 10 (inside). Settlement 4 to 5 m (13 to 16 ft). Because of settling under the water table the weight of the load will decrease. A compensating load in the calculation has been added. Result: a settled levee 8 m (26 ft) above ground level with 5 m settled under water.

Table 5 Soil schematization for settlement calculation

depth - ground level		**depth- zero level**	**unit weight**		**void ratio**	**compression index**		**OCR*σ'**	
Ft	**m**	**m**	**lb/cu ft**	**kN/m^3**	**e_0**	**Cc**	**C'**	**t/ft^2**	**kN/m^2**
2	0,61	1,52	110	17,29	1,36	0,42	12,94	0,475	45,49
31	9,45	10,36	101	15,87	1,89	0,78	8,53	0,425	40,7
47	14,33	15,24	100	15,71	2	0,81	8,53	0,65	62,24
67	20,42	21,34	99	15,56	1,94	0,98	6,91	0,85	81,4
87	26,52	27,43	106	16,66	1,58	0,67	8,87	0,85	81,4
122	37,19	38,10	102	16,03	1,5	0,77	7,48	1,35	129,28
147	44,81	45,72	125	19,64	0,75	0,24	16,79	1,5	143,64
162	49,38	50,29	107	16,81	1,34	0,67	8,04	1,75	167,58

$$S = \Sigma \frac{h}{C'} \ln\left(\frac{\sigma'_n}{OCR * \sigma'_o}\right)$$

with :

$S = settlement$

$h = thickness\ \ of\ \ compressible\ layer$

$C' = compression\ index$

$\sigma'_n = new\ effective\ stress$

$\sigma'_o = existing\ effective\ stress$

$OCR = over\ consolidation\ ratio$

Figure 67 and Figure 68 show the results of settlement calculations made with MSettle. Horizontal and vertical scale are not equal. Load, soil layers, settlement of the different layers and the piezometric levels of the different layers have been indicated.

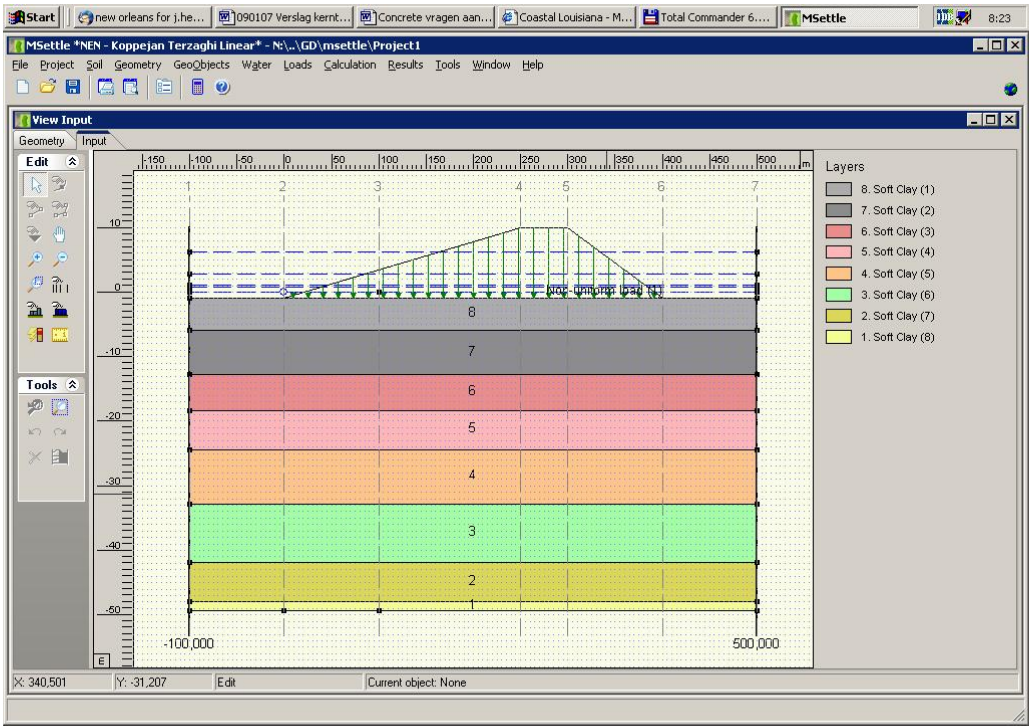


Figure 67 Settlement calculation (horizontal and vertical scale not the same): original geometry plus embankment

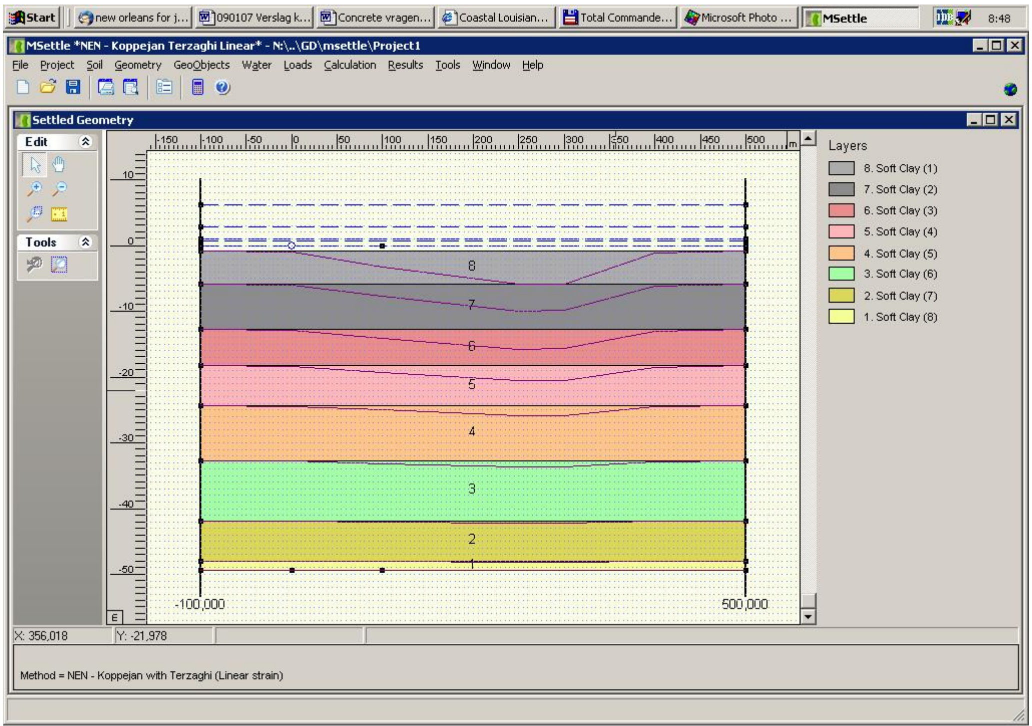


Figure 68 Settlement calculation (horizontal and vertical scale not the same): settled geometry

Stability

American calculations for unconsolidated soil are shown in enclosure F LACPR report Engineering Investigations were modified for consolidated soil.

Dutch approach (based upon Mohr Coulomb and Archimedes):

$$\tau = c' + \sigma' \text{ tg } \varphi'$$
$$\tau = c' + (\sigma_{total} - u) \text{ tg } \varphi'$$

with:

τ = shear stress
c'= drained cohesion
σ' = effective stress
σ_{total} = total stress
u = pore pressure
φ' = friction angle

Calculations have been made for reach 1 (Enclosure F)
Levee height 40 ft, inside slope 1 : 4 and 1 : 10.
Also calculated has been the influence of 70% excess pore pressure (30% consolidation).

Correlations between undrained and drained strength have been made based upon Technical Report V Appendix 2 page 35. From the undrained strength mentioned in enclosure F pag 189 the drained strength has been estimated.

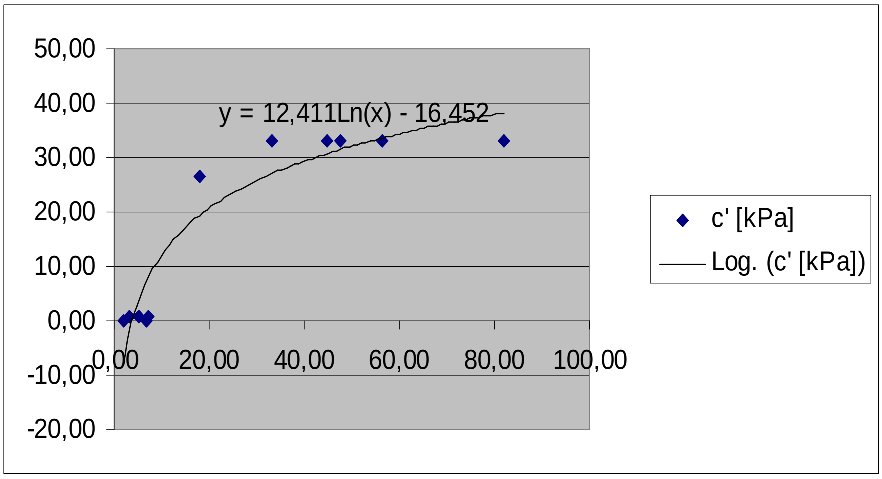


Figure 69 Correlation undrained cohesion c_u with drained cohesion c'.

For an undrained cohesion around 10 kPa a drained cohesion 10 kPa is calculated, which is not a realistic value (this value should be lower)

tangent of friction angle	friction angle [°]
0,25	14
0,5	27
0,75	37

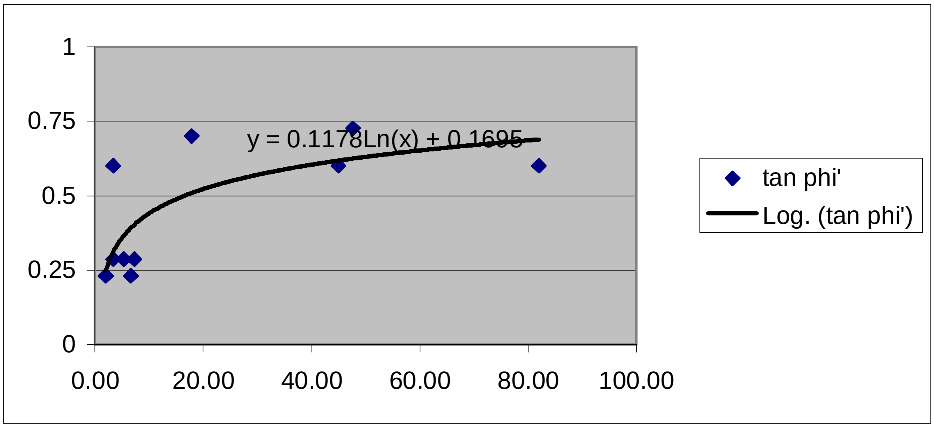


Figure 70 Correlation undrained cohesion c_u with tangent of drained friction angle φ’

Table 6 Soil schematization for stability calculation

layer number	depth - ground level ft	m	unit weight pcf	SI	undrained cohesion c_u psf	kPa	drained cohesion c’ kPa	friction angle phi’
5	-15	-4,57	95	15,22	200	9,58	11,6	23,5
6	-30	-9,14	100	16,02	200	9,58	11,6	23,5
7	-45	-13,72	100	16,02	312,5	14,96	17,1	26,0
8	-60	-18,29	100	16,02	462,5	22,14	22,0	28,1
10	-75	-22,86	100	16,02	612,5	29,33	25,5	29,6
11	-90	-27,43	100	16,02	762,5	36,51	28,2	30,7
12	-105	-32,00	100	16,02	912,5	43,69	30,4	31,6
13	-130	-39,62	100	16,02	562,5	26,93	24,4	29,1

Table 6 presents the soil schematization used in a stability calculation based upon above mentioned correlation. As an alternative to these calculations, additional calculations have been made with 10 kPa reduced to 2 kPa.

For orientation some stability calculations have been made with Bishops method of circular slip planes.

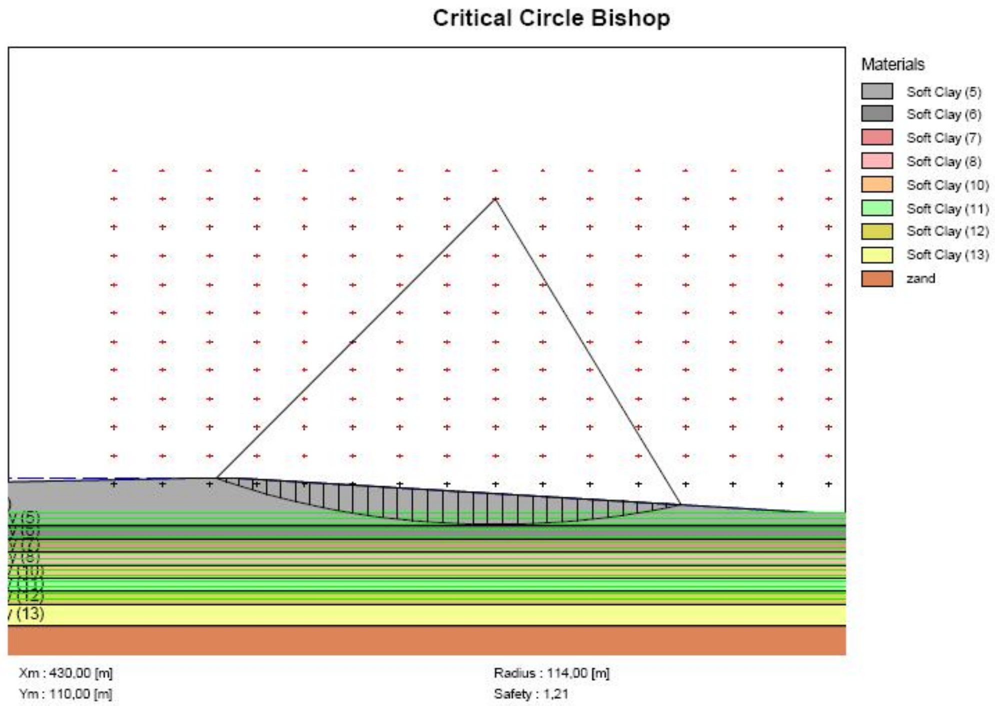


Figure 71 Levee of silty material, stability slope 1 : 10, layers above SL – 13,72 m limited drained cohesion, excess pore pressure 70% of load (consolidation 30%)

Without excess pore pressures the calculated safety factor is 1,82.
With excess pore pressures the safety reduces to 1,21.
Generally, these values for levees in the Netherlands are accepted.

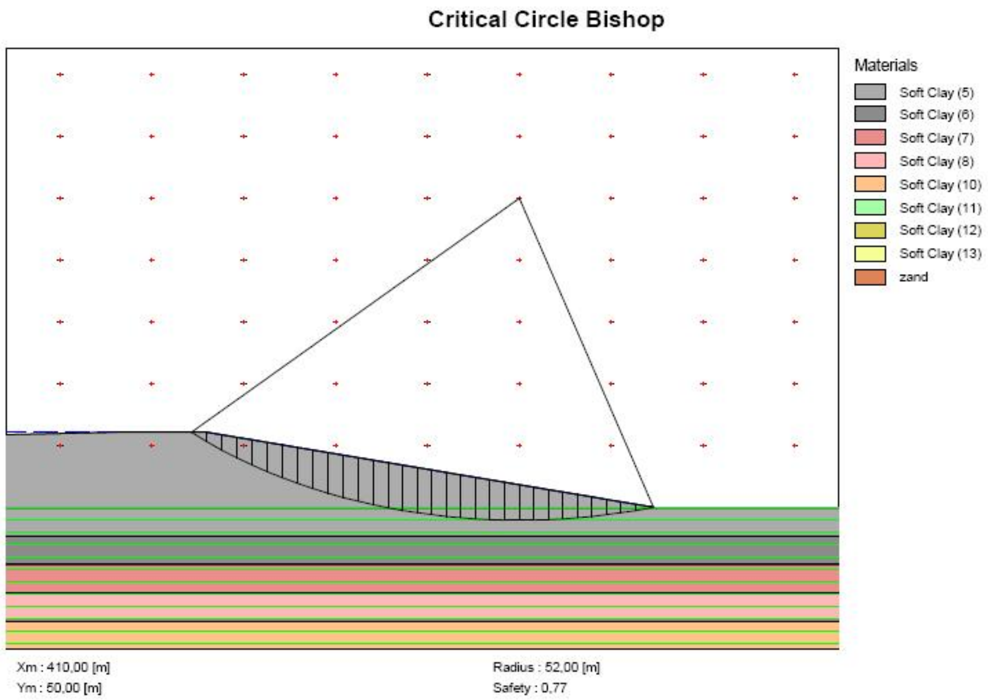


Figure 72 Levee of silty material, stability slope 1 : 4, layers above SL – 13,72 m limited drained cohesion, no excess pore pressure

Without excess pore pressures the calculated safety factor is 0,77.
This value is below the generally in the Netherlands accepted value.

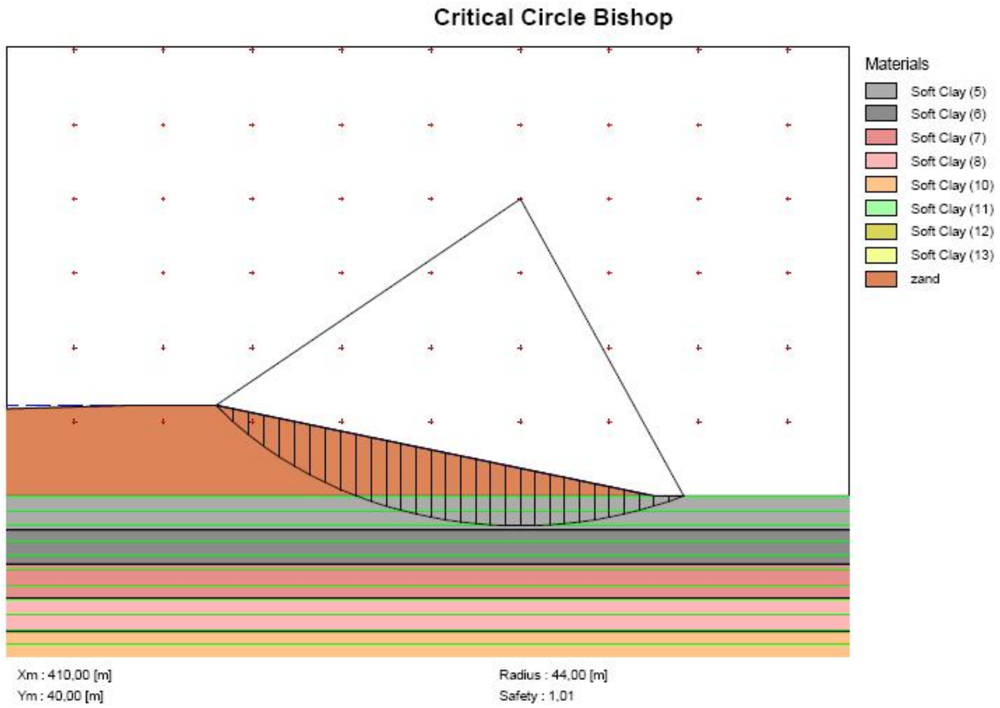


Figure 73 Levee of sand, stability slope 1 : 4, layers above SL – 13,72 m limited drained cohesion, no excess pore pressure

Using sand the stability factor raises to 1,01, a little to low for a permanent situation.
A slope with an added horizontal part will do.

However, this calculations are only made for macro stability. Other phenomena's such as erosion or micro-stability can, and probably will, mean that extra measures have to be taken along the surface of the levee, at the waterside as well as the crest and the landside.

Figure 74 Levee near Hook of Holland, Netherlands, with steep slope landside, silty material, after heavy rainfall. Newspaper photo.

Construction

During construction consolidation is poor.

The US practice is based on improving the subsoil by mix in place techniques (Figure 75, picture from internet).

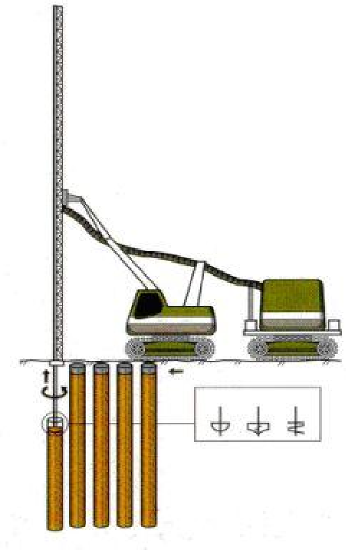


Figure 75 Schematic representation of improving the subsoil by mix in place techniques

In the Netherlands improving strength properties of weak soil by staged construction is usual. Dutch practice is based upon the decreasing of the pore pressures. This can be accelerated, for example by vertical strip drains (see Figure 76, picture from internet).

Figure 76 Inserting vertical strip drains to decrease pore pressure

Hydraulic fill is not excluded, but pore pressures should decrease as soon as possible.
Piezometer devices are used for monitoring.

Dry fill is not at all considered as a better way of filling then hydraulic fill, as long as good drainage is made possible. Soil is heightened in layers of one ore two feet thickness and compacted by rollers or bulldozers. In very weak areas making the beginning of the construction of an embankment can be a problem. Small excavations and soil improvement with coarse sand, or in the worst case, use of geotextiles may be necessary.

Erosion

To have some idea about the erosion, calculations have been made for the following conditions:

- Surge level 10 m;
- Wave heigth 5 m;
- Wave period 14 sec;
- Spilling waves: if surf similarity number < 0.5, which in this case would mean a slope more gentle than 1 : 16.

Design details: overtopping and erosion
Surge 10 m. wave 4-5 m, period 14 sec

Heavily armored 270 < q < 800 l/m/s = massive overtopping: crest height 11 m (10*1.1)
Lightly armored 30<q<90 l/m/s = light to moderate overtopping: crest height 12 m (10*1.2)
Grass q<10 l/s/m = non overtopping: crest height 15 to 18 m (10+ run-up 2%)
Notice: correlation with heavy rainfall

Design details: seaward structure (steep) slope
Surge 10 m. wave 4-5 m, period 14 sec
Slope 1:4
Armor weight 3,000 to 6,000 kg
Thickness 2 D50= 1 to 2,5 m
Under layer 10%= 300-600 kg
Dutch practice for no criteria at all for grass and clay layer:
wave height 5 m gives low wave attack if slope shallower than 1:100

or if slope shallower than 1: 30 and wave height <1.5 m
or if slope shallower than 1: 16 and wave height <0.8 m

Conclusions and recommendations

- Subsoil: improvement of soil properties by mixed in place techniques is unusual in the Netherlands; accelerating the decrease of pore water pressures in the subsoil and the increase of effective stresses is common use. Settlements of approximately 60% of the elevation are expected.
- Toplayer: to be able to construct a levee in shallow water or marshland it may be necessary to excavate the toplayer (2 or 3 feet), to replace it by sand, as coarse as possible, and to fill with the same material until above the water level. Use of fascine mattresses or geotextiles is restricted to special cases.

- Levee: hydraulic fill is not considered as an inferior method, dry filling by trucks ‘over the head of the fill’ is not recommended. Staged construction in combination with monitoring of pore pressures is usual practice.
- Levee: most of the available material is silty. This material is fine and compressible, has little permeability and has little cohesion, and it is described as poor building material. However, it is not completely unapt for building. Because of the little cohesion the maximum of friction should be mobilized, and this means dewatering. The more sandy the material is, the better it can be used in a levee core, but it has to dry as soon and as much as possible. In case of hydraulic filling it should be spread in thin layers, employing the advantages of the warm climate, and compacted by bulldozers. Dewatering can also be improved by adding horizontal sand layers, as a sandwich construction. However, in this silty material only gentle slopes can be made, which means that a lot of this inferior material and much space will be needed. In case of hydraulic filling much dredging capacity will be necessary. The construction phase will be critical due to the need to reduce the pore pressures. When in use, in case of high water outside, stability will not be the main problem, due to the impermeability of the material, the gentle slopes and the short stage load. Erosion is the more important mechanism then.
- Levee: use of structures in or upon a soil construction is not recommended. Irregular settlements under the levee and horizontal movements of structures may create space for penetrating water and undermine the structure. Furthermore overtopping water will fall down over the top of the structure and may cause extra erosion.
- Protection and covering: in case of very gentle slopes spilling waves instead of breaking waves are to be expected. In the Netherlands, a covering layer of good clay in combination with a good grass cover appears to be sufficient. Depending of the duration of loading by surge and/or waves, loss of material can be accepted as long as the levee does not fail completely.
- If selected material can be used, steeper slopes may be possible. For optimizing more geotechnical data (drained cohesion and drained friction angle) and data about availability and costs should be collected. A covering layer of only clay and grass will not be sufficient in that case.
- Most important of all: after construction a system for regular inspection and repair of failures should be installed.

F.2 The design of levees and other structures

Introduction

- No work has both the most economical initial investment and at the same time the most economical operation and maintenance (O&M).
- No work is most effective, that is in a natural situation, as nature is the best engineer of sustainable life and its supporting physical systems
- Sustainability and reversibility is best provided if levees are built with local (soil) materials
- Use the natural forces of nature as good as possible; transport of sediment by river water and by the tides and waves; growths of trees and plants to protect for hurricane tidal

wave; natural separation and sedimentation of soil particles in the estuary in order to build different sub locations suitable for specific natural developments
- Realize the gradients of fresh to salt water as natural as possible to enable these to further develop an equilibrium themselves
- Using local soil as building materials for levees is chosen for economic reasons
- Hydraulic transport of soil material is chosen if millions of m^3 of soil materials are needed (as will be the case in long levees) (no costs for buying materials and only costs for labor, machine hire and fuel results in fast, cheap and environmental friendly construction of levees)
- Local ‘improvement production’ of soil construction materials like sand and clay, from locally dredged material is probably more economical than hauling it from far
- Excavating of soil can be done by cutter-suction dredge best if soil is needed nearby (within 10 –20 km), delivering a soil-water mixture at the construction site by pipeline
- Transport of dredged material can best be done by trailer hopper dredge if distances are over 20 km and a suitable waterway is available
- Use of more expensive materials as stones, concrete, asphalt and steel should be kept to a minimum because of initial costs, O&M and costs for improvement in the future
- Look both at the present initial construction costs and long term O&M. Try to optimize this in balance with each other
- Eco-engineering involves active interactions with disciplines like ecologists, soil specialists, biologists, geologists and so on. This has been done from the start of the design process.

Levees

Text to be reworked

Hypothesis: the locally to be dredged materials are suitable for local levee construction, provided the width of the levees is in balance with the soil parameters. Such balance was clearly not found for the levees along the MGRO canal, that were built with material dredged from MRGO. It is evident that the dredged material was firm enough to form such a levee. However, overflow during hurricane Katrina wiped out the levees built this way as a result of erosion. The relatively narrow cross section proved not sufficient to withstand the surge during hurricane Katrina sufficiently long. Redundancy was lacking.

Traditional levees:
- Levees are made of sand on top of the existing subsoil, covered and protected with a watertight layer of special flexible stone-asphalt.
- The levees will be constructed of sand dredged in the Mississippi river, or other suitable sand borrow area nearer to the construction site, pumped into the construction site into the levee profile by hydraulic transport.
- If the subsoil is too soft to built the levee on it directly. Consider preparing the levee base dredging away the softest top soil layer over 3 m of depth
- As a first sand layer the top level is chosen on MSL + 1 m, spread with a spreading pontoon, in order to take care of careful application of an evenly spread load on the soft subsoil and to enable the next construction step.

- Installation of vertical drainage system in the levee base at locations where this is needed for construction phase stability. This drainage system may be needed for fast initial settlement as well.
- Successive layers of hydraulic fill sand on top of the first one with a thickness of 3 m
- Profiling the levee sand body with bulldozers. This ensures compaction as well.
- Cover of the levee with one layer of 0.2 m of sand asphalt (7 % bitumen) and a top layer of 0.2 m fully filled stone asphalt. Together these two materials form a strong, flexible, yet watertight layer, even under extreme settlement conditions of the levee. At the sea side toe of the levee, the layer thickness is more to allow for an elevated water table in the levee after a storm surge. At the inner toe, a water energy dissipation structure has been included. At the crest of the levee an air vent has been included to prevent blowing up of the water (and probably air tight) levee cover.
- As an extra, for ecological reasons, a strip of elevated (fines from the hydraulic fill or locally dredged) material can be added the seaward side to accommodate (or quick start) the required natural developments.

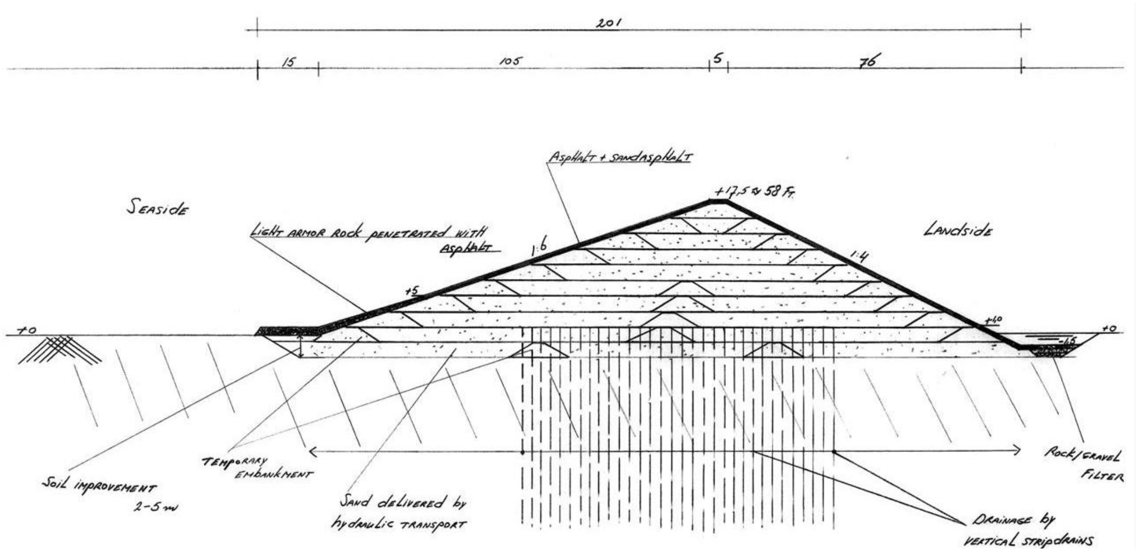


Figure 77 Typical cross section for a traditional levee design (measures in metres)

Eco-levees:

- It should be kept in mind that there is no practical experience with eco-levees. Therefore the assumptions made in designing these levees must be examined, preferably in the near future by means of experiments. The following assumptions were made in order to be able to make a technically feasible design and cost calculations.
- Eco levees are made of locally dredged material on top of the existing subsoil with no protected cover. The wide bulk of the levee can be eroded during a storm surge without total collapse as a protective measure. The growth of vegetation and trees will eventually form some kind of additional protection.
- The levees will be constructed from material in the borrow area near the construction site, pumped into the levee profile by hydraulic transport.
- The top of a first sand layer is chosen at MSL + 1 m to prepare for the next construction step.

- Depending on the bearing capacity of the subsoil, successive layers of hydraulic fill on top of the first one with a thickness of between 1 and 3 m will be possible. Material separation will be provided at the pipe outlet and the dump area in order to gain height.
- Most fines and clay will be directed to the seaward side of the levee in order to form the required locations and elevations of suitable material for vegetation. Clay production for protection and improvement of upper slopes for vegetation is included.

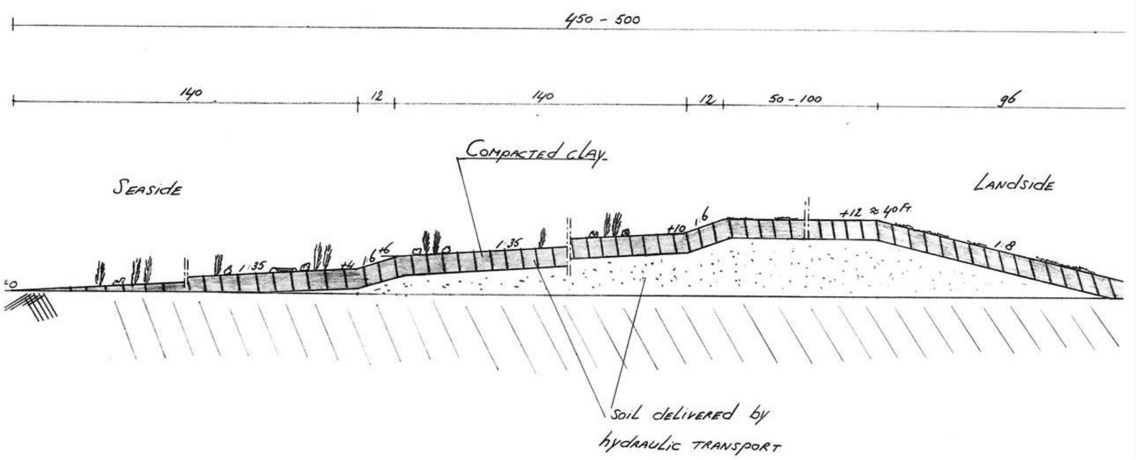


Figure 78 Typical cross section for an eco-levee design (measures in meters)

Structures

Flood protection structures are generally expensive and difficult to implement. Operation and maintenance is a concern. Vulnerable elements may need a lot of care. Generally, structures are to be considered as week spots in levee ring systems.

This section describes the following four types of structures:

- Surge barriers of 40 and of 15 m wide, allowing shipping,
- In- and outlet structure for free flow of water, acting as a surge barrier
- Sediment and river water inlet structure

Surge barrier in the Gulf Intracoastal Waterway (GIWW)

The main functions are (1) to enable navigation during the (vast) majority of time and (2) being able to be closed and function as a surge barrier during a storm event. Dimensions required are 40 m wide opening and a sill depth of 7 m for shipping. The elevation has to be chosen in relation with the location (mostly in a levee). The top level can be between 1 and 3 m lower than the top level of the levee.

The solution chosen is a double sector gate, well known as a reliable solution, both in the US but also worldwide, including the Netherlands. At locations where smaller shipping should be able to pass a levee, a similar surge barrier can be used with a width of 15 m.

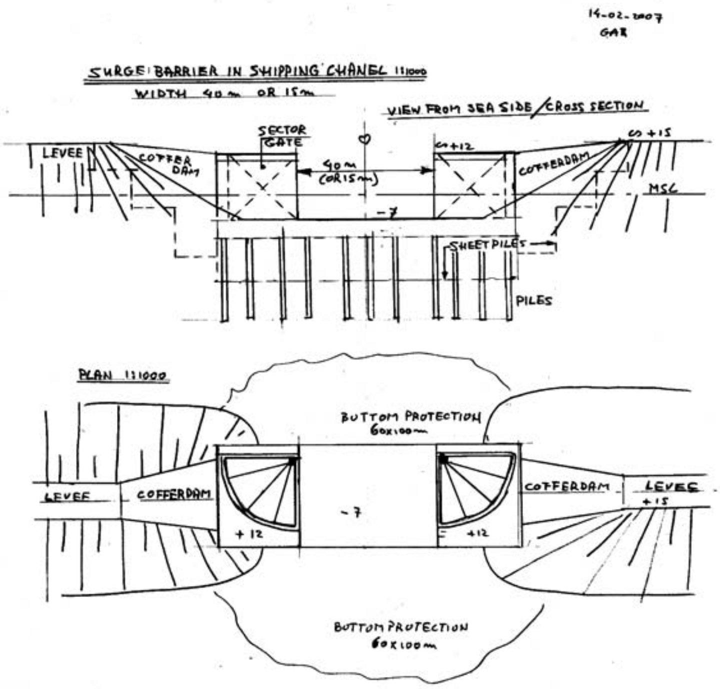


Figure 79 Top view and cross section of a surge barrier in a navigation channel.

In- and outlet structure for free flow of water, acting as a surge barrier

During normal circumstances this structure must allow for the exchange of water in such a way that environmental values are not influenced negatively. This means that the levee in which this structure is located should be as permeable as the water course is in the present situation. This can be realized by a series of openings, for which the total cross section equals the surface area of the cross section of the existing waterway. During a storm event the gates must be closed and form a surge resistant element in the levee. The top level can be a little lower than the levee in which it is located.

The solution chosen is a concrete wall structure with a number of 20 m wide and 5.5 m high openings. The number of openings should be adapted to the specific needs of the location in which it will be used.

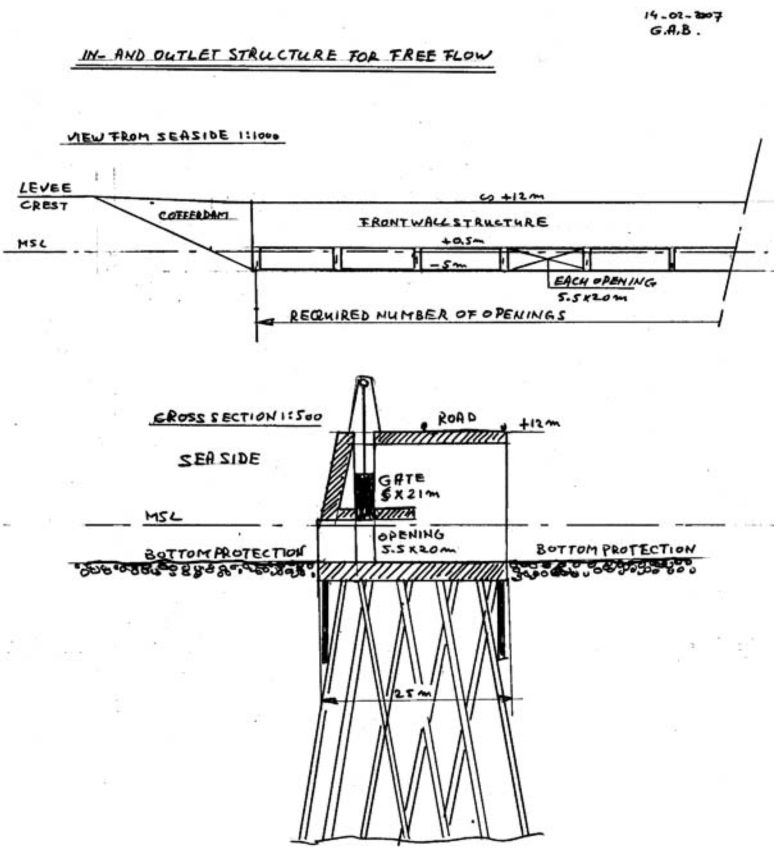


Figure 80 Top view and cross section of an in- and outlet structure, only to be closed during extreme events.

Sediment and river water inlet structure

This structure has to divert a substantial amount of sediment form the river over a long period of time in order to help build up marshes and areas that have eroded or subsided. It is in fact meant to be a nature-building device.

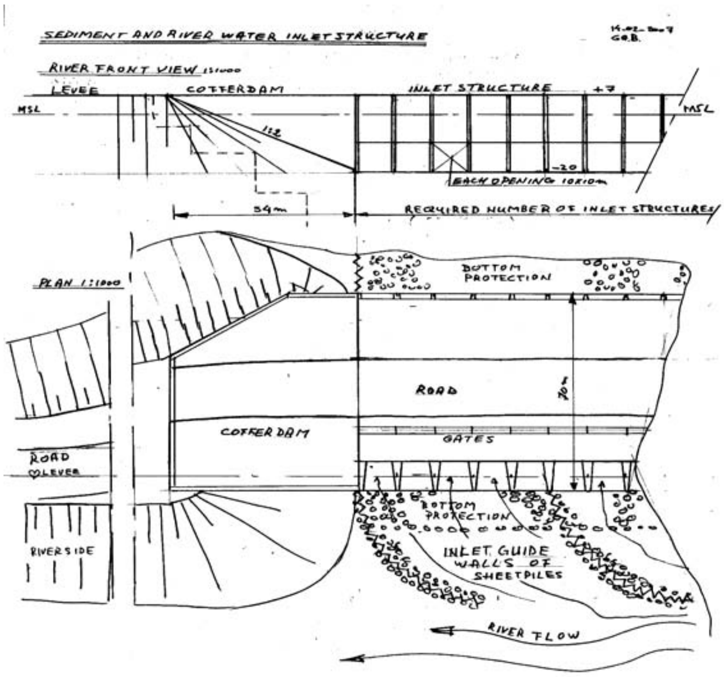


Figure 81 Top view of a sediment and river water diversion structure.

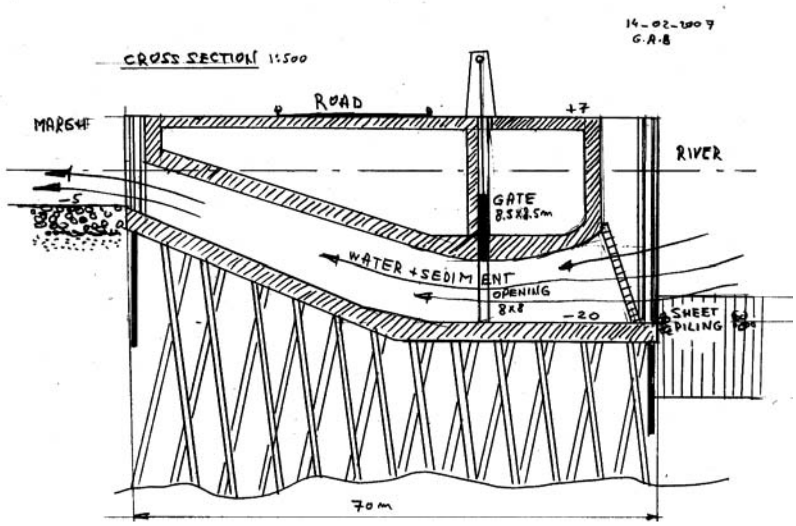


Figure 82 Cross section of a sediment and river water diversion structure.

The solution chosen is a deep concrete inlet structure to divert river water with the highest sediment concentrations, using the natural water flow from the river to build up the marshes. It acts as an artificial, controllable and adjustable equipment to build up the natural areas. For further detailed design of this structure, an intense interaction with various disciplines will be needed in order to get the best results.

A series of these structures, each of which can divert about 500 m^3/s, can be combined to create a large total diversion capacity.

G Potential measures and strategies

This appendix is- in our view - roughly 70 percent complete.
The description of various measures needs to be checked and completed.
Maps indicating the location of the various measures will be added..

G.1 Introduction / non-structural measures

In flood risk management, generally two types of risk reduction measures are considered:
1. structural measures; and
2. non-structural measures.

Non-structural measures generally comprise the following measures:
   a) flood proofing of buildings in order to reduce damages in case of flooding;
   b) the provision of flood early warning systems;
   c) development of evacuation plans;
   d) zoning and land-use measures, aimed at reducing potential flood damage; and
   e) the provision of flood insurance schemes.

Only limited attention will be devoted to non-structural measures for the following reasons:
- Flood proofing of buildings is generally only feasible in rural areas and in case the potential flooding depth does not exceed one floor level. In coastal Louisiana, this measure is already widely implemented, for example on Grand Isle.
- Weather forecasting and flood early warning systems are already in place and function well, as proven during hurricane Katrina.
- Also evacuation plans are already largely in place, as proven during hurricane Katrina. Elements of evacuation planning will most likely be improved in the near future, including for example the organization of mandatory evacuations, during which transportation has to be arranged for in particular the sick, the elderly and people lacking means of transportation.
- Zoning and land-use measures can be quite effective in minimizing flood damages. In the Netherlands and other European countries, land-use is strictly regulated, and the development of new houses or industries in floodprone areas outside a levee system is prohibited. In the US setting, where governmental interference with land ownership is not popular, strict zoning regulations will be hard to accept. The Dutch team considers such measure as not practical for coastal Louisiana.
- Insurance schemes are in place in the US.

The following sections focus on structural measures only for the metropolitan area of New Orleans and in the Pontchartrain and Barataria basins, respectively.

The following sections of this appendix provide an overview of the measures that were identified by the project team for each of the five categories of measures, which differ in time scale, effect and intention. Flood risk reduction is the main point of entry for this grouping:
1. Direct protection of incorporated values;

2. Closed basin hurricane surge protection;
3. Measures to consolidate and increase present natural surge reduction;
4. Basin surge reduction measures; and
5. System Interventions for long-term natural surge reduction.

G.2 Measures for direct protection of incorporated values

The following table provides an overview of the measures in this group of measures aimed at the direct protection of built-up areas. The table is followed by a more detailed description of these measures.

Location	**Upgrade existing levee**	**New levee**
Levees		
North of New Orleans	**NL1**	**NL2** additional lake front gated levee
East of New Orleans	**EL 1**	**EL2** new levee + MRGO open for navigation (port potential) + gate in GIWW
		EL3 new levee + MRGO closed (no navigation possible) + gate in GIWW
West of New Orleans	**WL1**	**WL2** new levee + overtopping buffering space
Plaquemines East		**PEL1** new levee
		PEL2 new levee + overtopping buffering space
Plaquemines West	**PWL1**	**PWL2** new levee + overtopping buffering space
Lafourge	**O1**	
Storm surge barrier		
Mississippi river (down-stream New Orleans)		**MG** gate in Mississippi, near Pointe à La Hache

Levees on the North side of the City of New Orleans, along Lake Pontchartrain

For this location, the project team identified two alternatives: NL1 (improvement of the existing levees) and NL2 (a new levee in front of the full length of the existing levee). For both alternatives, the existing or to be renewed pumping stations and a new storm surge barrier with two sector doors and an opening of 40 m (sea sketch in Figure 79) to the Industrial Canal must be considered and integrated in the design. Safety for the city, drainage water management and navigation are important aspects to consider. A main driving factor could also be attractiveness of the new levee for use as a boulevard for the City of New Orleans.

NL1 Improvement of the existing levees. Levee NL1 follows the alignment of the existing levee. The existing levee profile is not high enough for extreme hurricane events. Heightening of the levees to MSL +10.5 m is assumed in case the land bridge between Lake Borgne and Lake Pontchartrain surge reduction is realized. Without such surge reduction, the height of the levee is assumed MSL +12 m. *(when IPET water level / frequency numbers become available, these figures will be updated.).* Levee improvement along the entire length on the landside of the existing levee is technically speaking most attractive. Given intensive land use on the land side, however, this study assumes that improvements will made on the lakeside. At the location of the Industrial Canal, a storm surge gate will be incorporated in the levee. The existing and to be renewed pumping stations are incorporated in the levee as well. The water surface between the existing levee and the new levee could

be used as a buffering area for the temporary storage of pumped drainage water in case during high water levels as the lake the gates have to be closed.

NL2 New levee in front of full length of existing levee. Levee NL2 is located at some distance in the lake, in front of the existing levee. When constructing a new levee in front of the existing one, including a storm surge barrier, there are no longer extreme hydraulics loads on the existing levee. A new area of water between the existing and the new levee is created which can be used as temporary water storage, easing the water discharge problems in the city during a storm when the lock is closed. Existing pumping stations can remain in the existing levee. A new boulevard can be incorporated in the levee.

Levees on the West side of the City of New Orleans
Levee WL1 Improvement of existing levees Southwest of New Orleans (like in the multiple lines of defense plan by USACE). Nature development towards the marshland side of the levee, by means of increasing elevation to required levels for optimum eco development.

Levee WL2 New levee West of New Orleans, length as short as possible, some space existing built-up area for urban expansion. Nature development towards the seaside, by means of increasing elevation to required levels for optimum eco development.

Levees along Plaquemines
Levees PEL1, PEL2, PWL1 and PWL2: Plaquemines levee district. A ring levee will protect this parish. The safety level can be chosen according to the values at stake.

Levees along other urban areas (**to be checked**)
Levee O1 Lafourge levee district. Improvement of the existing ring levee around this town. The safety level can be chosen according to the values at stake here.

Levees along other urban areas
Gate MG Storm surge barrier in the Mississippi, near Pointe à la Hache

G.3 Measures for closed hurricane surge protection

The following table provides an overview of the measures in this group of measures for closed basin hurricane surge protection. The table is followed by a more detailed description of these measures.

Location	Measure (code + brief description)
Pontchartrain Basin	**PontLA2** gated levee barrier C90 **PontLB2** gated levee barrier along I10
Barataria Basin	**BARL** gated levee barrier in between Lafourche and Plaquemines (GIWW alignment)

PontLA2: new open levee barrier, essentially following the alignment of highway C90, with openings to allow exchange of water between Lake Borgne and Lake Ponchartrain, potentially realized by heightening the level of C90. Storm surge gates are built in the openings in the levee (Chef Menteur and Rigolets). These gates will only be closed when a

storm surge is anticipated. Traditional levees at these locations have an inner slope of about 1:4 and an outer slope of about 1:6.

PontLB2: new levee barrier, essentially following the alignment of Interstate I10, with openings to allow exchange of water between Lake Borgne and Lake Pontchartrain. Storm surge gates in these openings will only be closed when a storm surge is anticipated.

BarL: gated levee system between Lafourche and Plaquemines (GIWW alignment)

G.4 Measures to consolidate and increase present surge reduction

The following table provides an overview of the measures in this group. The table is followed by a more detailed description of these measures.

Location	**Measure (code + description)**
Strategic dumping	**MDUMP:** strategic dumping of Mississippi dredge from maintenance dredging activities in the Birdfooth to supply coastal areas
Pontchartrain Basin	
Levees	**PontLA1** new open levee barrier C90, open to the Gulf, heighten interstate road C90 **PontLB1** new open levee barrier, heighten highway I10
Fresh water diversions	**PontFW1** fresh water diversions Lake Borgne **PontFW2** fresh water diversions Lake Pontchartrain (Bonnet Carré)
Marshland Stabilization	**PONTMS** spotted marshland stabilization = closure of existing channels. Start in priority areas where most effect can be expected (marshland priority maps) Variants: limited closure vs complete closure of channels
Marshland Protection	**PontMP1** *Short term*: constructed low sand barrier islands. Goal: reduce wave energy on saltmarshes. Question: enough energy in system? Local sediment probably does not add to barrier islands. Present barrier islands consist of retreated sand. **PontMP2** *Long term*: underwater sediment buffer creation
Marshland creation	**PontMC1** sediment diversions Lake Borgne (Note: link met PontFW1) **PontMC2**: increased fine sediment load by pipe solutions (close to New Orleans) (if PontMC1 proves not efficient) **PontMC3** enlarged sediment diversions Carnarvon **PontMC4**: increased fine sediment load by pipe solutions (further from urban area) (if PontMC3 proves not efficient)
Barataria Basin	
Infrastructure	**BARINFRA** ‘culverts’ in existing interstate and railway
Fresh Water Diversion	**BARFW1** existing fresh water diversion New Orleans **BARFW2** extend existing fresh water diversions (Bayou Lafourche): recover normal flow
Marshland stabilization	**BARMC1** small scale sediment diversions **-** stabilization of marshlands along side the levees. Goal: contiguous fresh water swamps alongside the Mississippi. **BARMC2** increased fine sediment load by pipe solutions (If BARMC1 not sufficient) **BARMS** spotted marshland stabilization = closure existing channels. Start in priority areas where most effect can be expected (marshland priority maps) Variants: limited closure vs complete closure of channels

Strategic dumping of dredged material

MDUMP strategic dumping of material dredged from the Mississippi navigation channel (maintenance dredging, some 7 to 10 million ton annually) in coastal areas.

Pontchartrain Levee Alignment A

PontLA1 new open levee barrier, essentially following the alignment of highway C90, potentially realized by heightening the level of C90, with openings to allow exchange of water between Lake Borgne and Lake Ponchartrain. (Chef Menteur and Rigolets).
Because some flood water can be safely stored in lake Pontchartrain during a hurricane, the openings in the levees do not have to be closed completely during a storm surge. Therefore, the levee has erosion resistant openings. Traditional levees at these locations have an inner slope of about 1:4 and an outer slope of about 1:6.

Pontchartrain Levee Alignment B

PontLB1 new open levee barrier, essentially following the alignment of Interstate I10, with openings to allow exchange of water between Lake Borgne and Lake Pontchartrain. Because some flood water can be safely stored in lake Pontchartrain during a hurricane, the openings in the levees do not have to be closed completely during a storm surge. Therefore, the levee has erosion resistant openings. Traditional levees at these locations have an inner slope of about 1:4 and an outer slope of about 1:6.

Pontchartrain Fresh Water

PontFW1 fresh water diversions Lake Borgne. Measure aimed at ensuring long-term environmental sustainability by means of fresh-water swamp revitalization.
PontFW2 fresh water diversions Lake Pontchartrain (Bonnet Carré). Like PontFW1, but aimed at Lake Pontchartrain.

Pontchartrain Marshland Stabilization

PontMS spotted marshland stabilization, mainly achieved by closing existing canals. Start in priority areas where most effect can be expected (marshland priority maps). Variants: plugging or complete closure of canals.

Pontchartrain Marshland Protection

PontMP1 *Short term*: construct new, low sand barrier islands with the objective to reduce wave energy on salt marshes. Question: enough energy in system? Local sediment probably does not add to barrier islands. Present barrier islands consist of re-worked sand.
PontMP2 *Long term*: underwater sediment buffer creation.

Pontchartrain Marshland Creation

Alternative A:
PontMC1 sediment diversions Lake Borgne (Note: link met PontFW1)
PontMC3 enlarged sediment diversions Carnarvon

If Alternative A is not expected to be sufficient, then consider alternative B:
PontMC2 increased sediment load by piped sediment supply (close to New Orleans)
PontMC4 increased sediment load by piped sediment supply (further away from the urban area)

Barataria Infrastructure
BarINFRA 'culverts' in existing interstate and railway

Barataria Fresh Water
Set of measures for LT environmental sustainability:
BarFW1 existing fresh water diversion New Orleans
BarFW2 extend existing fresh water diversions (Bayou Lafourche): recover normal flow

Barataria Marshland Stabilization
Alternative A:
BarMC1 small-scale sediment diversions - stabilization of marshlands along levees. Goal: contiguous fresh water swamps along the Mississippi River.
If BarMC1is not expected to be sufficient, then alternative B:
BarMC2 increased fine sediment load by piped solutions

Barataria Marshland Stabilization
BarMS spotted marshland stabilization (closure of existing canals). Start in priority areas where most effect can be expected (marshland priority maps). Variants: plugging or complete closure of canals.

G.5 Basin surge reduction measures

The following table provides an overview of the measures in this group of basin surge reduction measures. The table is followed by a more detailed description of these measures.

Location	Measure (code + description)
Pontchartrain Basin	**PontSR1** open levee surge reduction Lake Borgne **PontSR2** open levee surge reduction + longer variant of PontSR1 **PontSR3** outer surge reduction: high sand barrier islands
Barataria Basin	**BARSR1** open levee surge reduction (GIWW alignment), overtopping **BARSR2** open levee in between Lafourche and Pointe à la Hache **BARSR3** outer surge reduction: sand barrier islands

Pontchartrain Surge Reduction
PontSR1: open levee system (eco-levees) aimed at surge reduction, crossing Lake Borgne. This alignment offers the advantage that current land use on the land bridge remains unaffected and that the land bridge itself is also protected. Slopes of eco-levees are gentle: about 1:8 for the inner slope and about 1:35 for the outer slope.

PontSR2: like PontSR1 but following another, longer alignment. Further outside, on the marshes East of Lake Borgne, all the way to Pointe à la Hache.

PontSR3: outer storm surge reduction: a string of new barrier islands

Barataria Surge Reduction
BarSR1: open new levee surge reduction by means of eco-levees, located at the Gulf side of GIWW, connecting Jesuit bend at the Mississippi levee and the landward side of the Lafourge levee. Slopes of eco-levees are gentle: about 1:8 for the inner slope and about 1:35 for the outer slope.

BarSR2: open new levee further seaward than BARSR1, connecting from Deer Range to the seaward side of Lafourge levee and in between Lafourche and Pointe à la Hache

BarSR3: outer surge reduction: sand barrier islands

G.6 Interventions for long-term natural surge reduction

The following table provides an overview of the measures in this group of measures for long-term natural surge reduction. The table is followed by a more detailed description of these measures.

Location	**Measure (code + description)**
Crevasse building Pontchartrain Basin	**PONTCR** Crevasse building for long term marshland creation (alter shape of active lobe). Learning by doing. Creating new sub-delta's, enhancing natural process: • Large scale diversion Mississippi • Key role MRGO ('firehosing' with MRGO') • Crevasses East of New Orleans (± 15% of the river water) • New shipping channel **PONTCR_S** small-scale crevasse building **PONTCR_L** large-scale crevasse building
Crevasse building Barataria Basin	**BARCR** Crevasse building for long term marshland stabilization. Creating new sub-delta's, enhancing natural process: Large scale diversion Mississippi Crevasses West of New Orleans (± 15% of the river water) **BARCR_S** small-scale crevasse building **BARCR_L** large-scale crevasse building
Birdfoot	**BF1** tidal shortcut Birdfoot on both sides. Goal: create new Birdfoot **BF2** large scale crevasse on one side, flexible after 10 years. Example: Atchafalaya

Pontchartrain crevasse building

PontCR: Crevasse building for long term marshland creation, expected to alter the shape of the active lobe. Learning by doing. Creating new sub-deltas, enhancing natural process:

- Large-scale diversion Mississippi
- Key role MRGO ('firehosing' with MRGO')
- Crevasses East of New Orleans (about 15% of the river water)
- New navigation channel

PontCR_S: small-scale crevasse building
PontCR_L: large-scale crevasse building

Barataria Crevasse building

BarCR : Crevasse building for long-term marshland stabilization. Creating new sub-deltas, enhancing natural process:

- Large-scale diversion Mississippi River
- Crevasses West of New Orleans (about 15% of the river water)

BarCR_S: small-scale crevasse building
BarCR_L: large-scale crevasse building

Birdfoot

BF1: tidal shortcut Birdfoot on both sides of the river, with the objective to keep the sediments close to the existing coastline.

BF2: large-scale crevasse on one side, flexible after 10 years. Example: Atchafalaya

H Strategy development and impact assessment

The work covered by this appendix is part of the second phase of the project and has not really started yet, except for a composition of the various alternative strategies.

H.1 Strategy development for Risk Reduction and Landscape Stabilization

The main purpose of the planning process is to find to best set of measures to reach the overall objectives for flood risk reduction and landscape stabilization, possibly enhancing the local and regional economy. To focus evaluations and recommendations, the project team designed three alternative strategies that differ significantly in overall effect. These strategies are shaped on what the Dutch team considers to be the most important planning decision for the future of the Mississippi Delta; whether or not to close off the basins with (gated) barriers and change the present (natural) state into managed land and water.

The three strategic alternatives for both the Ponchartrain and Barataria basins are therefore formulated according to this key planning principle:

4. Open Estuary System
5. Semi Open Defense System
6. Closed Defense System

From a strategic point of view, protecting incorporated values against hurricane surges by means of surrounding levees and floodwalls is an accepted and effective way of flood risk reduction and the system might be enhanced to cope with more extreme events to provide an adequate protection level. These are proven measures that, in principle, could be implemented in a relatively short time period (set aside budget and land ownership complications) and would serve to be the primary protection.

Landscape stabilization is a secondary but important means to add sustained safety in the long term, thus introducing the multiple lines of defense principle. The ‘open’ system for the long term relies heavily on the effectiveness of landscape measures that are (probably) complicated and difficult to plan and implement. Can the Mississippi Delta be restored to both serve ecology and safety? Intensive research and pilot projects are required to start finding effective and economic solutions for large-scale restorations. A ‘closed’ defense system avoids being reliant on landscape stabilization for risk reduction purposes and provides safety for a large area behind it. However, even equipped with gates to pass water, the structure will be a definite morphological and ecological barrier separating the basins into a fresh and saltwater area thereby loosing (some) of its important intermediate areas. The ‘Semi Open Defense System’ obviously tries to combine the better of the two extremes, but requires innovative solutions to achieve the goals of risk reduction.

H.2 Overview of measures in each strategy

Measures for a safe city

Each of the above mentioned three strategies consists of a set of measures for a safe city and a second set of measures for a sustainable delta. For the short-term protection of the city, the main question is to choose between upgrading the existing levees or building new levees (or a combination of these two options). The answer to this question depends on various aspects, including costs, but also depends on future space requirements for the city of New Orleans. The Dutch Perspective team will not be able to address the latter issue.

Another question is whether or not a storm surge barrier in the Mississippi is feasible. *(This will be addressed in the second phase of the project*).

Table 7 provides an overview of the measures and alternatives for a safe city.

Table 7 Measures in 'safe city' strategy.

	MEASURES SAFE CITY
LOCATION	
North NO	NL1 or NL2
East NO	EL1 or EL2 or EL3
West NO	WL1 or WL2
East Plaquemines	PEL1 or PEL2 (*Note: check existing levees)*
West Plaquemines	PWL1 or PWL2
Mississippi Gate	Yes or No (Mgate)

Alternatives for a sustainable delta

For a sustainable delta the project team identified three alternative strategies: an open Estuary System, semi Open Defense System and a closed Defense System. Depending on the type of strategy this will affect the heights of the levees for a safe city. For example, with a closed defense system the heights of the levees in the city of New Orleans can be lower than with an open defense system.

Open estuary system

Within the open sea defense strategy we distinguish three alternatives. An alternative with only upstream supply of water and sediment (Alternative 1). Important measures in this alternative are fresh water diversions and sediment diversions. On a small scale some experiments are carried out with crevasse building.

Additional to Alternative 1 also downstream supply of water and sediment is done in Alternative 2. At the sediment diversions the fine sediment load is increased by using pipe solutions. And at the seaward side some low sand barrier islands are constructed to reduce the wave energy on salt marches. Furthermore there is some strategic dumping of Mississippi dredge from maintenance dredging activities in the Birdfoot to supply coastal areas. In Alternative 2 the crevasse building to create marshland is done on a large scale.

Alternative 3 is in fact the short-cut of the Birdfoot combined with the creation of an under water sediment buffer which will probably form some sand barrier islands on the long term. An overview of the measures in these three alternatives within the open estuary defense system is shown in Table 8. In this table the additional measures in the next alternative (compared to the prior alternative) are shown in red.

Table 8 Measures in open sea defense strategy.

Strategy	**MEASURES OPEN ESTUARY SYSTEM**		
Alternative	**Alternative 1** **Only upstream supply of water + sediment**	**Alternative 2** **Up- and downstream supply of water + sediment**	**Alternative 3** **short-cut Birdfooth**
OBJECTIVES			
Stabilization & revitalization of natural system	PontFW1 + Pont FW2 BarFW1 + BarFW2 PontMC1 + PontMC3 + BarMC1 PontMS + BarMS (start in priority areas) BarINFRA	Equal to Option 1 plus + PontMC2 (instead of PontMC1) + PontMC4 (instead of PontMC3) + BarMC2 (instead of BarMC1) + PontMP1 + MDUMP	Equal to option 2
Crevasse building for long term mashland creation	PontCR + BarCR	PontCR + BarCR (large-scale)	PontCR + BarCR (large-scale)
Marshland Protection			+ PontMP1 + PontMP2
Minimization of sediment loss			BF1 or BF2

Semi-open sea defense strategy

The semi-open sea defense strategy relies on surge reduction measures in Lake Pontchartrain Basin and the Barataria Basin. In the Lake Pontchartrain Basin there are two lines of surge reduction measurs: one in front of the Lake near Lake Borgne and one along the small landbridge along the C90 or I10. These measures are taken in addition to alternative 1 of the open sea defense system. The semi-open defense strategy is defined as alternative 4. Table 9 provides an overview of the measures in the semi-open defense system.

Table 9 Measures in semi-open sea defense strategy.

Strategy	**MEASURES SEMI-OPEN DEFENSE**
OBJECTIVES	Alternative 4: Semi-open defense system
Stabilization & revitalization of natural system	Measures of alternative 1 of 'Open estuary system'
Marshland creation	Measures of alternative 1 of 'Open estuary system'
Surge reduction measures per basin	PontLA1 or PontLB1 (no difference in effect) PontSR1 or Pont SR2 or PontSR3 BarSR1 or BarSR2 or BarSR3

Closed sea defense system

The closed see defense system contains closed basin hurricane surge protection measures, mainly gated structures. These surge reduction measures by gated structures are taken additional to alternative 1. Table 10 provides an overview of the measures in a closed sea defense alternative.

So finally we distinguish five alternatives:

- Alternative 1: Open estuary system with upstream supply of water and sediment
- Alternative 2: Open estuary system with upstream and downstream supply of water and sediment
- Alternative 3: Open estuary system with a short cut of the Mississippi river in order to a minimization of sediment loss
- Alternative 4: Semi-open estuary system with surge reduction measures per basin
- Alternative 5: Closed sea defense system using gated structures.

In all alternatives contains spotted marshland stabilization by closing the existing channels in the wetlands.

Table 10 Measures in closed sea defense strategy.

	MEASURES CLOSED SEA DEFENSE
OBJECTIVES	Alternative 5: Closed sea defense system
Stabilization & revitalization of natural system	Measures of alternative 1 of 'Open estuary system'
Marshland creation	Measures of alternative 1 of 'Open estuary system'
Surge reduction measures per basin by gated structures	PontLA2 or PontLB2 BarL

Impact assessment: second phase of the project.

I Management and Maintenance

This appendix is- in our view - roughly 90 percent complete.
Figures and tables will be improved.
References will be checked and if necessary corrected

The Dutch perspective on LACPR is not confined to nature and technology. Management and maintenance of the present and future situation is essential for the performance of any coastal restoration and/or hurricane protection scheme.

I.1 Concepts of management and maintenance

I.1.1 Management considerations

Existing flood protection schemes must be maintained by management and maintenance. Improvement of structures or the entire scheme is needed if it shows weaknesses or if it does not meet the (changed) functional requirements. Given the changing conditions, management and maintenance does require monitoring. Monitoring of natural conditions, but also monitoring of the surroundings or society is necessary.

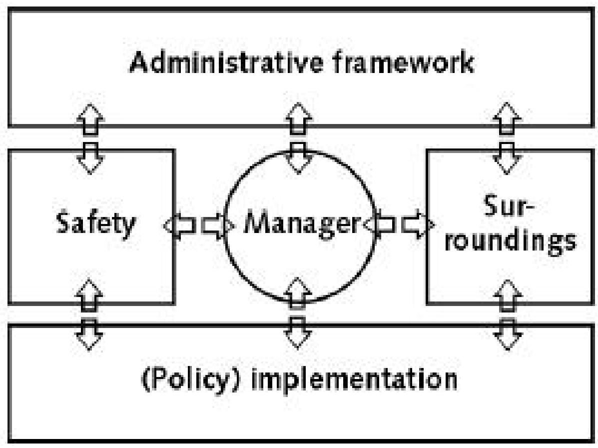


Figure 83 Managing flood protection schemes

New policies must be developed and implemented. And last but not least, the flood protection manager acts within an administrative framework.

Large infrastructural schemes such as flood protection schemes generally fulfill a number of functions. The main goal of management and maintenance is to ensure that the scheme performs to the required standards. This is called ‘functional quality’. Not meeting these standards leads to (functional) failure. This type of failure needs to be discerned from structural failure, which happens if the scheme loses its structural integrity. In general, management and maintenance is defined as the grand total of activities aimed at keeping the scheme at the required level of functional quality. In most cases this is a tougher demand than the structural integrity. Management and maintenance requires inspection, repairs, replacements and upgrade to ensure a longer lasting service time of the scheme.

Furthermore, it is vital to include future management and maintenance in the design philosophy of the scheme.

I.1.2 Design philosophy and risk-analysis

The design philosophy of flood protection measures is generally aimed at providing a certain predefined level of safety. This level of safety however can be expressed in many ways and to make things even more complicated various design techniques can be applied.

For example, the required safety level offered by any flood protection measure can be defined in a number of ways, using:

- natural events, such as ‘providing sufficient safety against a Cat. 5 hurricane’ or ‘being able to withstand the maximum recorded water level’
- statistical terms in combination with natural events, such as the ‘100 year flood’ or the ‘1,000 years hydraulic load’
- consequences, such as ‘the flooded area is limited to …. area’ or ‘the number of casualties is limited to ….’
- statistical terms in combination with consequences, such as ‘the yearly probability of damages exceeding ….. is limited to ….’ or ‘the yearly probability of a number of casualties exceeding …. is limited to ….’.

Dealing with natural hazards means dealing with uncertainties and probabilities. It is therefore inevitable that statistical terms and probabilistic design techniques are used to design flood protection measures. In order to assess whether a technical system, such as flood protection measures, meets the required standards risk-analysis can be applied.

The risk-part of risk-analysis incorporates the probability of various events and the consequences of these events. Generally speaking, risk is the product of probability and consequences. Any risk-analysis is aimed at quantifying both factors. Uncertainties are generally included in assessing the probability of an event.

Such a risk-analysis may be focused on various items:

- analysis of the technical system and its components
- probabilities and uncertainties of loads and strengths of the system and its components
- balancing the cost of an improved system and the expected damages of failure
- optimization of the system
- prioritization of measures to improve the overall performance of the system.

In any risk-analysis it is important to discern the ultimate limit state (ULS – loosing structural integrity) and the serviceability limit state (SLS – loosing functional performance). If the risk-analysis is focused on the consequences of any natural hazard this distinction will take place automatically. If the risk-analysis is kept simple, this distinction must be guarded thoughtfully.

Assessing the safety of any flood protection scheme starts with the system as a whole. This system is constructed using a (large) number of components, each with its own threats, loads, failure modes and so on. A fault tree or an event tree can be used to illustrate this behavior of the flood protection scheme.

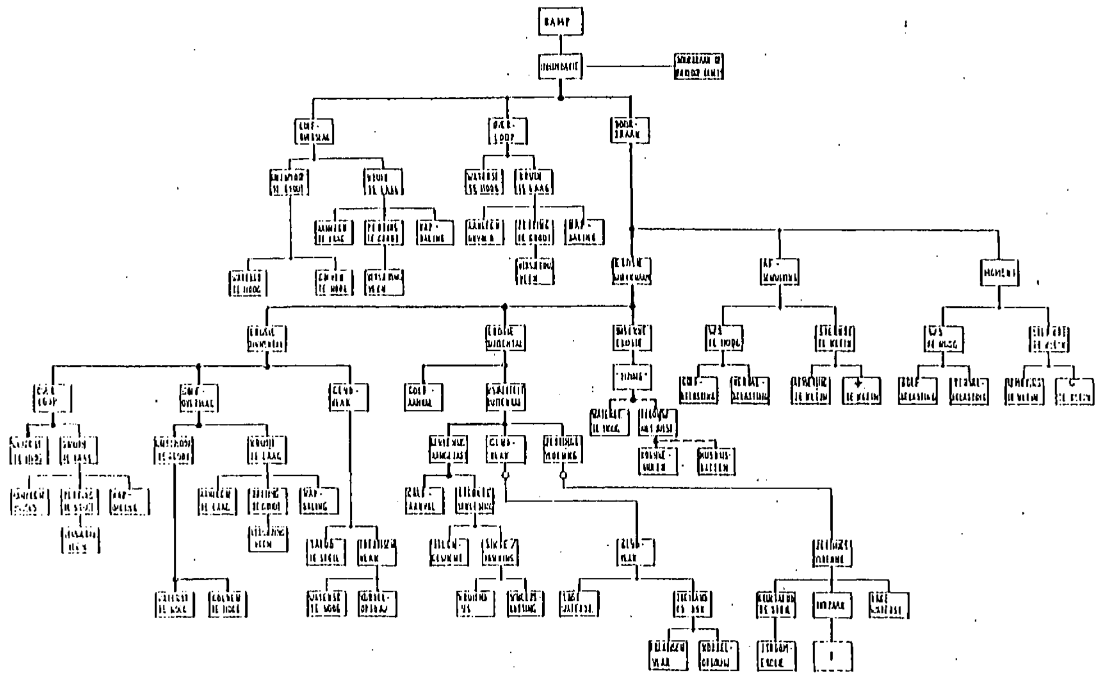


Figure 84 Example of an event tree

Preparing an event or fault tree requires a lot of craftsmanship and knowledge about the behavior of the flood protection scheme. The techniques of preparing an event or fault tree is largely a supporting technique for the designer. The designer remains responsible for the description and likelihood of the various failure modes. Literature studies, empirical data, interviews and so on may prove to be helpful to quantify the various events or failures.

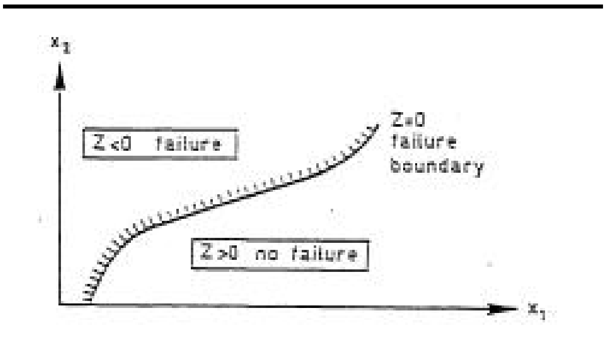


Figure 85 Reliability function

To derive a probability of failure two methods can be applied. The first method is using experience or intuition by estimating the probability of failure. The second method is to perform a probabilistic calculation. This second method requires a model to describe the behavior of the scheme or component. Based on this behavior a so-called reliability function is derived. The probability of failure equals P(Z<0). Such a reliability function is depending on water level, crest level, slopes and so on. Most of these variables have a stochastic character.

Estimating the probability of failure several techniques can be used:

- Level III: including the full probability density functions
- Level II: a simplified method in which the probability density functions are replaced using normal distributions

- Level I: a further simplified method using characteristic or design values for the various variables and (partial) safety factors. Strictly speaking this method does not yield a probability of failure but depending on the application and the design philosophy such a method can be applied very well.

Calculating a probability of failure of a flood protection system automatically leads to the question 'how safe is safe enough?'. This question can be answered from at least two points of view:

- individual risk, indicating the risk for an individual
- societal risk, indicating the risk for the society as a whole.

Each of these points of view will lead to its own conclusions.

Further information on design philosophy in general can be found in the Fundamentals on Water defense laid down by the Dutch Technical Advisory committee on Water defense [?].

I.1.3 Changing conditions

Changing conditions will force the responsible authorities to evaluate and re-evaluate both the technical and functional state of the solutions. The changes arise from:

- Nature: sea level rise, climate change,
- Structural: settlement, structural degradation,
- Society: economics, population,

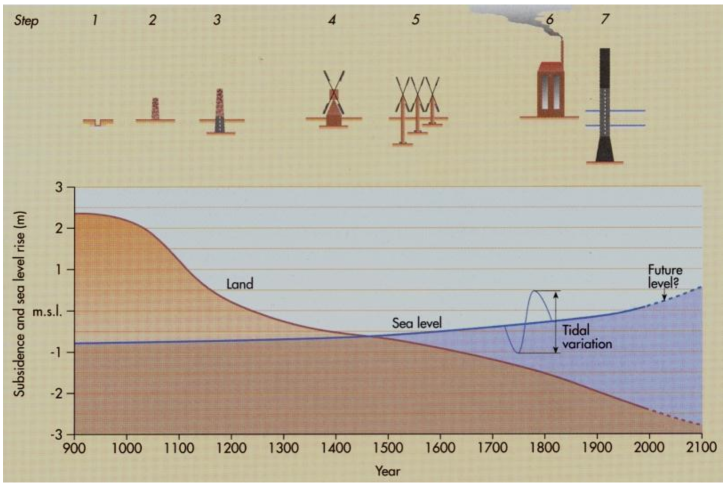


Figure 86 Sea level rise and settlement (over time)

The event or fault trees mentioned before share on common drawback: the probability of an event occurring or not leads to a rather binary approach. However in flood protection most of the mechanisms have a more continuous character. Most of the parameters determining both the probability of failure and the consequences of failure will vary in time.

Sea level rise will lead to increased probability of failure, settlement of levees will lead to increases probability of failure and urban development will lead to increased damages in case of a flood. This means that these developments in time will have to be addressed in the design philosophy. A lifetime approach in the design of a flood protection system is therefore necessary. And that is where the relation between design and management & maintenance becomes clearly visible.

1.1.4 Strategy, tactics and operations

To describe this relation in more detail, it is essential to discern strategic, tactical and operational maintenance. Operational (day-to-day) and tactical (everything for the next 5-10 years) maintenance are both focused on the technical quality of the solution. Operational maintenance is not meant to combat changing conditions, except for the structural degradation. Tactical maintenance considers all changing conditions except for the societal conditions. Strategic maintenance is focused on the matter: how safe is safe enough, given the changes in society?

Further information on the distinction between strategic, tactical and operational maintenance can be found in Jorissen [?].

1.1.5 Maintenance concepts

Maintenance concepts may vary depending on the properties of the solutions, the costs of maintenance, the predictability of failure, the consequences of failures and so on. In general two main classes of maintenance strategies can be discerned : corrective and preventive maintenance. Corrective maintenance means that the object will be repaired after failure. This strategy is applied if the consequences of failure of the object are relatively small. In hydraulic engineering this strategy is not applied very often because of the large consequences of failure. However, this assumption is not valid for all components of hydraulic infrastructure. Therefore, more and more components are maintained using the corrective maintenance strategy, which is in most cases extremely cost effective.

Several preventive maintenance schemes are available. The most advanced and generally the cost effective option is based on the actual condition of the object. However this requires a good description of the behavior of the object (= deterioration model). Preventive maintenance requires always a form of inspection besides repair. Costs of inspection have to be taken into account when deciding for a maintenance strategy. Other options are time based and load based. Time based preventive maintenance is based on fixed intervals. These intervals may be based on experience or modeling. An intermediate form of preventive maintenance is load based. According to this strategy maintenance is done for example based on the number of passages of a shipping lock.

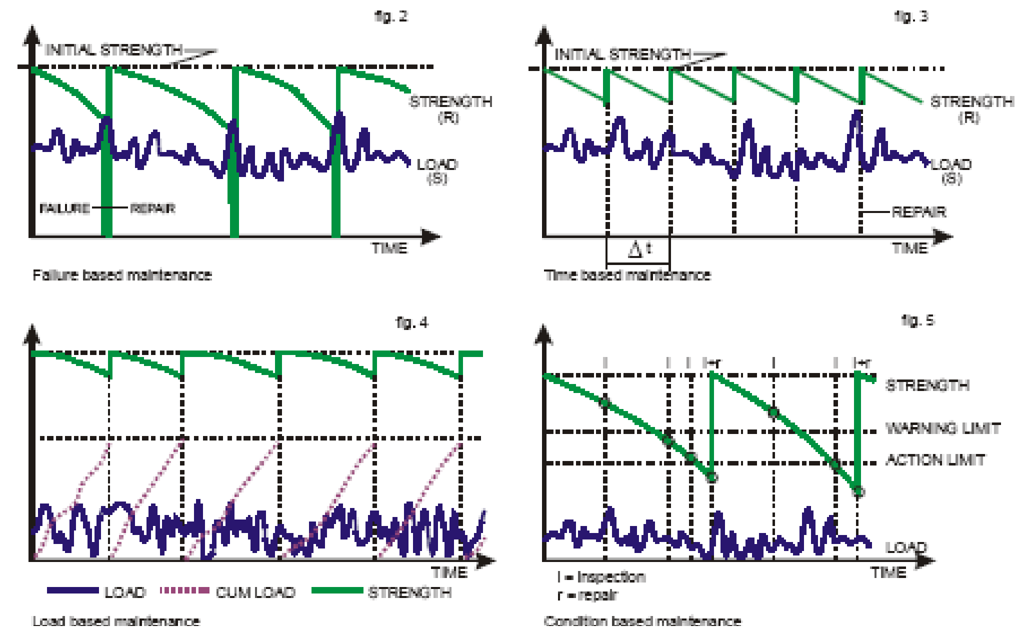


Figure 87 Maintenance concepts

Research and monitoring is aimed at improving the deterioration models and inspection techniques in order to apply the conditions based preventive strategy as much as possible for the vital components of the object. If possible, corrective maintenance is preferred for the other components. These maintenance strategies are described further in the papers by Vrijling et al [?] and Jorissen et al [?].

1.2 Dutch perspective on management and maintenance

1.2.1 Present situation in The Netherlands

General

Figure 88 Flood prone areas in the Netherlands

Large parts of the Netherlands are threatened by floods, both coastal and riverine from origin. Obviously the North Sea poses a threat with storm surges entering this shallow sea from the Northwest. But also the major rivers Rhine and Meuse entering the Netherlands from the East and Southeast may cause flooding. About 60% of the population lives in flood prone areas and around 70% of the Gross National Product (450 billion €) is earned in these areas.

Throughout the centuries flooding and protection against flooding has always been a major issue for spatial planning and urban development.

Not only the extreme situations such a floods impose a problem on the Dutch. Some parts of the Netherlands lie so low (up to 18 feet below MSL) that water management in daily circumstances requires measures as drainage, pumping, storage and discharging into the sea or rivers.

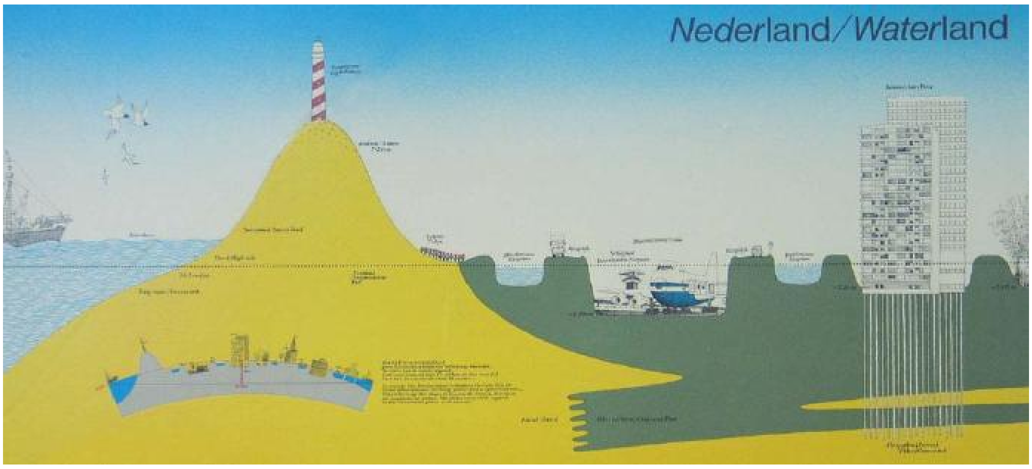


Figure 89 Cross-section

Figure 90 Primary flood protection structures

The flood prone areas are protected by so-called primary flood protection structures such as levees, dunes, barriers and other type of structures (such as locks). The total length of these structures adds up to 3,558 kilometers (2,211 miles).

The total length of additional flood protection structures, largely meant for internal drainage purposes adds up to a tenfold of this figure.

Safety

Looking back over the centuries is has always been the case that major steps in flood protection were taken following a flooding disaster ('no policy beats a calamity'). Even in the 20th century it took the 1916 and 1953 to the present flood protection system.

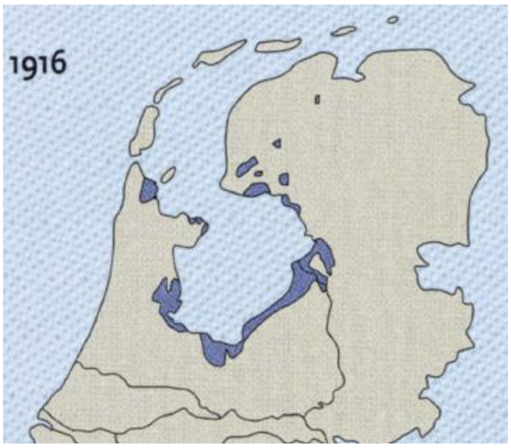


Figure 91 Extent of the flooding in 1916

The flooding in 1916 of the so-called ‘Zuiderzee area’, even Amsterdam was flooded, due to a storm surge on the North Sea, after which a 20 mile long dam was constructed, completed in 1932. After that land reclamation works were carried out, including large polders like the Wieringermeer, Noordoostpolder, and Flevoland.

The biggest disaster in recent history is the flooding in February 1953. Large parts of the Southwest of The Netherlands were flooded and 1836 people died. In retrospect, this disaster led to a major step forwards. The Delta plan, which was developed after the flood featured two main items: shortening of the coastline by closing off the estuaries and introducing safety standards for flood protection structures.

Figure 92 Extent of the flooding in 1953

Closing off the estuaries meant building large dams and barriers, including the Eastern Scheldt and Maeslant barriers. Only the most Southern estuary, the Western Scheldt, remained open because of the harbor of Antwerp. The Delta plan shortened the Dutch coastline by more than 700 kilometers (434 miles).

Figure 93 Safety standards for primary flood protection structures

The safety standards were derived on a economic basis, essentially following the same method as applied in Appendix E of this report. The required safety of the primary flood protection structures ranges from 1/10,000 per year to 1/1,250 per year. These figures stand for the inverse of the return period of the design hydraulic loads.

The 10,000 year return period is applicable for the areas with the highest economic values at stake and the most densely populated areas (which also includes the most of the major cities such as Amsterdam, Rotterdam and The Hague).

Surroundings

Although floods have been more dominant in the history of the Dutch, the acceptance of floods have changed significantly over the centuries. In the mind of the general public there is no such thing as an ‘inevitable flood’. This is a sharp contrast compared to the situation in the 19th century and before. Floods were considered to be ‘an act of God’.

Another important development is the enormous increase in consequences of floods. In the 19th century the river area was flood more or less regularly.

There were even a number of relief structures designed to create floods in the lesser populated or lesser important areas to protect important cities further downstream in case of a flood. At present such a relief structure would create enormous damages due to the increased population and ongoing developments.

On the other hand however, it has become more and more difficult to built and maintain large infrastructural element in this densely populated country. Lack of space in the urban areas is a limiting factor in designing and constructing new levees. And the historical, natural and cultural values of the existing infrastructure are increasingly considered to be worth saving.

The changed public perception of floods, the increased risks, the limited options for large-scale infrastructural measures and the increased appreciation of existing infrastructure are the key challenges for the present flood protection manager.

Policy

Figure 94 Main policy elements

The flood protection manager in the Netherlands however is helped by a clear policy. The main elements of these policies are:

- Spatial planning
- Coastal management
- River management
- Structural management
- Information and research
- Emergency management

For each element of this flood protection policy there are specific goals set:

- spatial planning: ‘water proofing’ urban developments;
- coastal management: to maintain the coastline at the 1990 position and to compensate for sand-losses in the foreshore;
- river management: to develop and maintain a river bed able to discharge the design discharges (return period 1250 years) safely; this means that the water levels during these floods are equal or lower than the 1996 design values;
- structural management: to maintain and reconstruct flood protection structures in order to meet the legally prescribed safety standard;
- information and research: to research the relevant natural, technical and societal developments and to disseminate the results in a comprehensive set of national guidelines;
- emergency management: to prepare emergency management plans and to have an emergency management organization standing by.

Traditionally, the elements of spatial planning and emergency management have always been the weakest links. Especially after 1953, introducing the vigorous safety standards and building the structures to meet these standards, the general public and most of the administrations too considered flooding risks to be insignificant. The focus on so-called preventive, structural measures (dams, barriers, levees and dunes) more or less led to a neglect of non-structural measures.

However, worldwide catastrophic flooding events and some minor flooding events in the Netherlands led to a change of this opinion. The topics of spatial planning and emergency management are nowadays the priorities to improve the preparedness of all administrations involved. Obviously, this also requires a much greater awareness and commitment of the general public too.

With regard to spatial planning the municipalities are obliged to involve the water boards in the process of developing municipal zoning plans. This allows the water boards to address the water management or more specific the flood protection issue in an early stage.

With regard to emergency planning the local and regional authorities (municipalities, water boards, provinces) have been improving their preparedness over the last decade. However, this preparedness is mostly limited to potential regional flooding problems. Extreme floods, threatening the nation, have not been addressed in the context of emergency management. The focus was always on preventive measures. However, recently Rijkswaterstaat has taken the initiative to deal with flooding disasters on a national scale.

The flood protection policy is well embedded in a general water management policy. This policy is based on integrated water management. The Netherlands form an important part of the catchments of four main European rivers: Rhine, Meuse, Scheldt and Ems. The Dutch water systems are a mixture of natural systems (rivers and sea) and human interventions (canalization, locks, levees, barriers). About 60% of the land surface needs protection against flooding. An extensive system of primary flood defenses provide an excellent standard of protection against flooding from the rivers and sea. But there is more, water systems provide other and essential functions, like:

- transport;
- surface water and groundwater for agriculture and industry;
- ecological values;
- recreational use;
- drinking water supply.

The water management main policy goal is therefore:

To have and to hold a safe and habitable country and to maintain and develop resilient water systems which allow a sustainable use

Integrated water management is the key to accomplish this audacious goal. By managing the water system (water, bottom and banks) as a whole based on assigned functions the Ministry of Transport, Public Works and Water Management focuses on realizing reference situations in the national water systems. With regional and international partners agreements are made to reach a similar approach for entire catchment areas.
In a functional approach the first step is to assign one or more functions to a water system. The number of possible functions can be very large. The Netherlands chose for 13 functions. The most common or primary functions are printed in Italics. The national management plan includes a detailed list of assigned function for each water system.

Functions		
Flood protection	Fisheries	Hydropower
Discharge of water, ice and sediment	Bank recreation	Drinking water
Transport	Recreational fishing	Commercial fishing
Water quality and ecology	Cooling water	Sand and gravel mining
Recreation		

Administration

Delivering the flood protection policy is the responsibility of public authorities. Flood protection management involves a number of these authorities. In fact all types of administrations (national, regional, local) are involved. The national government (Ministry of Transport, Public Works and Water management unless stated otherwise) is responsible for:

- setting the policy;
- legislation;
- issuing guidelines for design (voluntary) and safety assessment (mandatory)
- financing the reinforcement of primary flood protection structures (due to new safety standards, increased hydraulic loads associated with the safety standards and/or new knowledge on failure mechanisms);
- financing management and maintenance of the coast, rivers and large barriers
- national crisis management (Ministry of the Interior);
- management and maintenance of the coast, rivers and large barriers (Rijkswaterstaat);

The water boards are responsible for:

- management and maintenance of the majority (90%) of the primary flood protection structures and all regional flood protection structures;
- financing management and maintenance (local taxation).

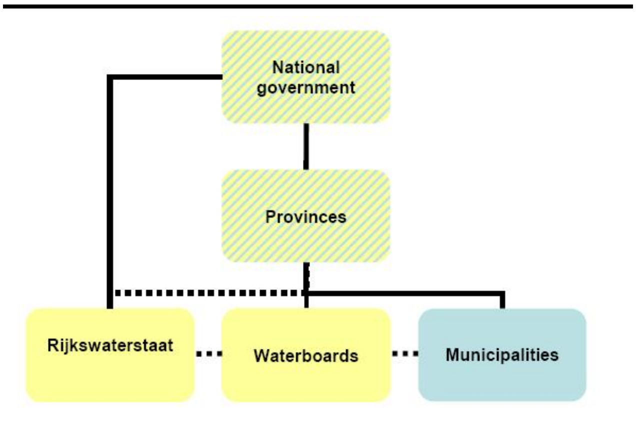


Figure 95 Administrations involved in flood protection

The provinces supervise both water boards and municipalities on a regional level. The provinces are also responsible for spatial planning and regional crisis management. With respect to flood protection, the municipalities are responsible for local crisis management.

Water boards

Central government, the provincial and the municipal authorities are familiar bodies and most people have some idea about what they do. The water board is less well known, which is only to be regretted, since water boards carry out essential tasks to keep the country habitable. The Netherlands cover about 34,000 square kilometers where land and water meet. A large proportion of the land is artificial. This originally water and wetland area has been reclaimed, drained and cultivated by people. It became suitable for habitation, building, agriculture and horticulture, industry and recreation. The Dutch seem to take these activities for granted and seldom realize the potential risk of the low location of the country. More than 50% would be inundated if there were no dunes and dams to protect property and goods against storms at sea and high water in the rivers. The Dutch feel safe. The care for flood protection and water management is business-as-usual. However, without continuous operating and maintenance of the many levees, locks, pumping stations, flood barriers, canals and ditches, the safety of more than nine million Dutch would be in danger.

The water boards are largely responsible for the essential aspects of regional water management. Nowadays this goes a lot further than constructing levees and operating pumping stations. The activities of the water boards are now also related to licensing discharges, treatment of urban wastewater, conservation and restoration of water systems, guiding water uses etc. Water boards are responsible for balancing the different interests in water management. This is done in co-operation with central government, provincial and municipal authorities and stakeholders. Water boards are public authorities. Unlike provinces and municipalities, water boards have limited legally defined tasks:

- Flood protection: maintenance of infrastructure (dunes, levees);
- Water management:
  - water quantity: drainage and irrigation, ensuring that it is kept at the appropriate levels;
  - water quality: combating water pollution and improving the quality of the surface water;
- Treatment of urban wastewater;
- (Sometimes) management of inland waterways and rural roads.

Stakeholders elect their own representatives in the water board assembly. Unlike general democracies where political representatives are elected, water boards can be characterized as ‘stakeholder democracies’. Categories of stakeholders (residents, landowners, owners of property) choose their representatives in the assembly. Dutch water boards have their own financing structure. They raise taxes to carry out their tasks. Two basic taxes are distinguished:

- the water system tax (for flood protection and dry feet) and
- the water pollution levy (for wastewater treatment and water quality management).

Both taxes recover the costs of water boards. In this respect they are self supporting.

A remarkable solution for making use of external funds is the Netherlands Water Board Bank. This financial institution was raised by water boards in a time frame when individual water boards were not eligible for loans at the private banks. In 50 years of existence the Bank has evolved to a reputable bank.

The Dutch water boards are united at provincial level and at national level. In this way, they are able to communicate with their main counterparts. The organization at national level is called the Association of Water Boards. The Association is the counterpart of ministries, the parliament and international institutions.

Finally, it should be mentioned that the water boards have undergone an enormous merging in the past 50 years. The number of water boards has gone down from circa 2,500 in 1950 to 12 at the moment. This process of merging has three main reasons. Firstly, the flood of 1 February 1953, during which 1,836 people lost their lives and enormous financial damage was brought about. This disaster marked the end of many small water boards. Secondly, the handing over of water quality control, including waste water treatment, to the water boards from 1970. After all, the responsibility of building and managing costly sewage treatment plants calls for a firm administrative and financial support. Thirdly, the government’s policy of setting up integrated water management, which means that the various responsibilities, i.e. surface water and groundwater in both quantitative and qualitative terms, should be

looked at in their mutual connection and, therefore, preferably brought together in one organization (the so-called ‘all in-water boards’).

Financing

Generally speaking the required budget for flood protection in The Netherlands is raised by taxation. Taxation on a national level raises the budget for all reinforcement works and for management and maintenance of the coast, the river and a limited number of barriers and levees. Taxation on a local level is used to cover the costs of management and maintenance of the vast majority of levees (90% of the primary flood protection structures and all regional flood protection structures).

Figure 96 National water management plan

The national budget for water management in general and flood protection in particular is allocated based on national water management plans. These plans include both (re)construction and management & maintenance of infrastructure. In these plans the link between policy, measures, costs and benefits are described.

Distributing the available national budget requires prioritization. This process is always difficult, but is absolutely necessary to keep the pressure like cost awareness and cost effectiveness. In the Netherlands prioritization is being done from three different viewpoints:

- political agreements (priority 1);
  1. priority based on functions :
  2. flood protection and discharge of water, sediment and ice
  3. transport using national water systems
  4. water quality and ecology
  5. transport using regional water systems
  6. other functions
- priority based on type of measures :
  – fixed maintenance before variable maintenance
  – project under construction before new tenders

This prioritization sequence within the national budget makes that flood protection measures is indeed one the key priorities in water management.
The budget of the water boards is raised by local taxation by the water boards. The water boards are allowed to raise taxes for water management purposes only. The provinces strictly supervises both the amount and destination of taxation. But nevertheless, this local taxation is a very efficient and effective method. Taxes are raised with a very specific purpose to a very specific population. And to close the cycle: that population is directly represented in the water board based on their taxation volume (and therefore their interest).

Water board taxation (figures 2004, in € per year)		
Charges based on property	Open land charge	60 € per hectare (10,000 m^2)
	Building charge	39 € per household
	Resident charge	39 € per household
Water pollution charge (50 €/unit)	Small business (1-3 units)	50-150 €
	Business (< 1,000 units)	< 50,000€ (based on accommodation)
	Business (> 1,000 units)	> 50,000 € (based on water consumption)
	Household (3 units)	150 €

Safety assessment

Especially for the function flood protection a separate legal instrument has been developed. Since 1996 the Flood Protection Act describes the flood protection standards and the safety assessment procedure attached to these standards.

In short:

- the national authority (ministry) issues guidelines to assess the quality of flood protection structures every five years;
- the guidelines contain the most recent information on hydraulic boundary conditions and technical criteria;
- the flood protection manager (water board and Rijkswaterstaat) make these safety assessments and report the results to the provinces;
- the provinces on their turn integrate the reports of the flood protection manager and report to the minister;
- finally, the minister report to both houses of parliament.

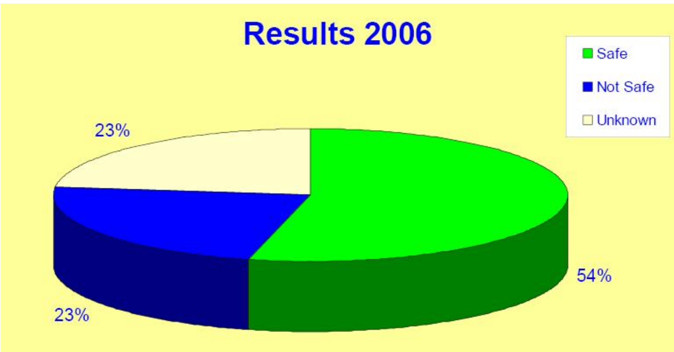


Figure 97 Result safety assessment 2006

The Flood Protection Act of 1996 enforces a safety assessment of all primary flood protection structures every 5 years. The results of the second national safety assessment still show a large fraction of uncertainty, largely due to insufficient information on in particular geotechnical aspects. The 23% that does not meet the standards are well-known stretches: coastal embankments (revetments) and geotechnical problems (dating from the reinforcement program without geotechnical research). The total of the required reinforcement program according to these results will add up to 1.6 billion €.

Developments

Three developments will enhance the future flood and water management policy and practice in the Netherlands:

- changes in safety philosophy;
- more attention for spatial planning and crisis management;

- international and especially European policies (and legislation).

Flood protection structures in the Netherlands have never been stronger: the probability of encountering floods has substantially declined since the last flooding in the Southwestern part of the Netherlands in 1953. However, the risks of casualties and of economic damage from flooding have become much greater since this event.

This controversial situation is the result of a growing discrepancy between the existent set of design standards for the height and strength of dams, levees, and coastal defenses set around 1960, and a steady social and economic development since that time. The average yearly economic expansion since 1960 has been twice as high as expected at that time and the population at risk in the Netherlands has more than doubled. In the period between 1960 and present the design standards have not been corrected for the increased economic value and population.

Compared to other risks, the societal risk of flooding (the probability of large numbers of casualties) in the Netherlands appears to be several orders of magnitude larger than the sum of the societal risk of other known external hazards (e.g. industrial hazards and plane crashes). A further increase in flood risk is expected both due to climate change (increased sea level rise and higher river peak discharges), and further economic and social development. To adapt the required safety an update of the risk-based safety standards is essential. It is also essential to incorporate another type of flood protection measures in the equation: non-structural measures such as spatial planning and crisis management.

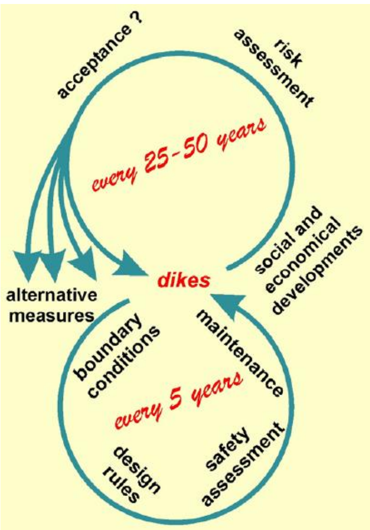


Figure 98 Safety and risk

In order to reduce the societal risk of flooding, strategies to reduce the probability and/or to reduce the number of fatal victims are appropriate. A further strengthening of levees would reduce the probability of a flood. However, one of the reasons for the increased societal risk is the growth of housing and infrastructure projects in the low-lying areas. So far, potential strategies to guide housing and other spatial developments such to avoid undue increase of risk have not been used in the Netherlands.

Policy requires a system of response mechanisms in case floods occur. An evaluation of the present situation has given cause for concern: small-scale, unrealistic training opportunities, emergency plans showing shortcomings and poor cooperation in some cases between managers of flood defenses and disaster-response organizations.

Figure 99 Coastal sediment system

Another important development is the increased international dimension. National borders do not limit floods and any other natural event. Especially in river systems the need for harmonizing measures is important, since various countries share the same river causing the flood. But also in coastal systems, the natural system has to be the basis for analysis and developing measures. The continuity of sediment-transport along the North Sea shores is an excellent example.

Future weak coastal links

A number of locations on the Dutch seashore will fail to meet the safety standards in the near future. As a proactive action the Ministry of Transport, Public Works and Water management asked the provinces to come up with solutions in which both the safety aspect and 'enhancing the spatial quality' were addressed. The Ministry made a budget of 740 million € available as an estimate for the reference designs for safety measures only. The provinces initiated a project organization with all authorities participating. So far, the provinces have come up with a number of integrated plans. The main problem however has been to find the required additional funds. In urban areas, the larger local municipalities were able to chip in. But in the more rural areas, additional funds were harder to find. National budgets for recreation and/or nature development are potential options, but the difficulty for the provinces is to coordinate or the combine these budgets in the plans for the weak links. This process is still ongoing at the moment. Around the summer of 2007 the Ministry of Transport, Public Works and Water management will assess the provinces' plans based on the safety requirements and the additional (with respect to the 740 M€) funding.

1.2.2 Present situation around the North Sea

Not only the Netherlands are threatened by coastal flooding in the North Sea area. Neighboring countries such as Belgium, Germany, Denmark and England all face to some extent the challenges from living on the sea shore.

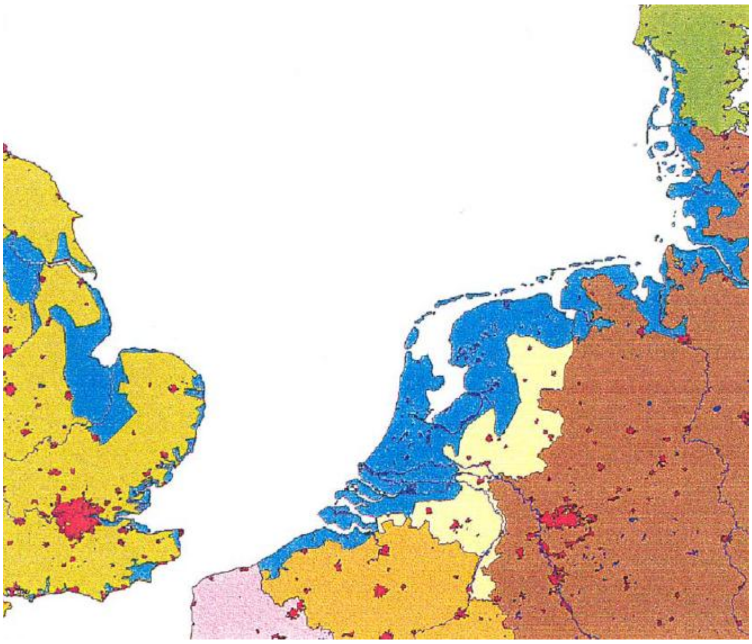


Figure 100 Coastal flooding around the North Sea

Rijkswaterstaat has participated in the COMRISK project (www.comrisk.hosted-by-kfki.baw.de). The objective of this project was to improve coastal flood risk management through the transfer and evaluation of knowledge and methods as well as pilot studies. One of the subprojects was specifically aimed at:

- providing a comprehensive analytical framework as a tool to properly assess policies and strategies;
- making an inventory of different levels (strategic, institutional, instrumental and operational) of coastal risk management in relation to the current national policies of the countries and regions in the North Sea Region involved in the COMRISK project;
- making an assessment of current national policies in terms of legal, social, technical, financial, socio-economic, ecological and managerial aspects (including the ICZM (Integrated Coastal Zone Management) principles for sustainability).

It showed that a wide range of flood protection policies has been developed in the countries and regions depending not only on the scale of the potential flooding problem (ranging from 70% to less than 1% of area and/or GNP). The legal, social, financial, socio-economic, ecological and managerial context is very decisive. This has resulted in various flood protection policies (criteria, standards, legislation, operation and management):

- UK: generally cost-benefit analysis (although indicative safety standards exist), permissive legislation, mix of centralized and de-centralized operation and management
- Denmark: population at risk, technical standards, permissive legislation, centralized operation and management
- Germany: technical standards, permissive legislation, centralized operation and management (at the level of the so-called states)
- Belgium: technical standards, permissive legislation, centralized operation and management (at the level of Flanders)

- The Netherlands: legal safety standards, prescriptive legislation, mix of centralized and de-centralized operation and management

Country	Flood prone area [Km^2 and %]	Capital at risk [Billion €]
England and Wales	2,200 (5%)	250
Denmark	< 1%	No data
Germany	3%	No data
Belgium	11,000 (18%)	No data
The Netherlands	25,000 (70%)	2,000

1.2.3 Present situation in New Orleans

General

The area of greater New Orleans is surround by water: the Mississippi river, the Gulf of Mexico, large lakes such as Pontchartrain and Borgne. Combined with the low lying, densely populated areas, this leads to significant potential flooding risks. These risks are continuously growing because of sea level rise, settlement, urban development and coastal erosion. During Katrina large areas of the New Orleans area were flooded.

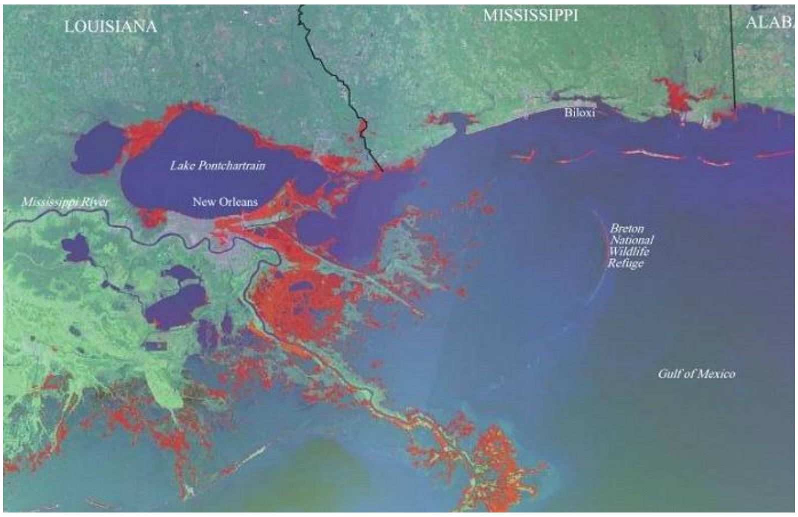


Figure 101 Flooding during Katrina

During the flood more than one million state residents were displaced, over 1,400 people died, over 200,000 homes were damaged and approximately 200 square miles of marshes were destroyed.

Flood protection is provided by river levees and hurricane protection schemes. The internal drainage is provided by a large number of pumping stations.

Figure 102 Levees and pumping stations

The internal drainage is important because of the characteristics of the urban area of New Orleans: low lying areas with hardly any storage areas.

In order to prevent flooding during rainfall nearly all the rain has to be discharged into Lake Pontchartrain via three major outfall canals.

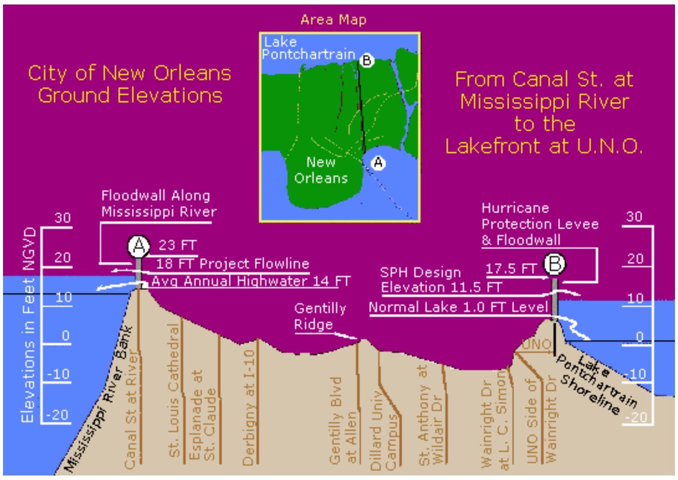


Figure 103 Cross-section

The flooding during Katrina had two main causes: overtopping of earthen levees in the Eastern parts of the city and geotechnical failure of flood wall (I-wall) in the centre of the city.

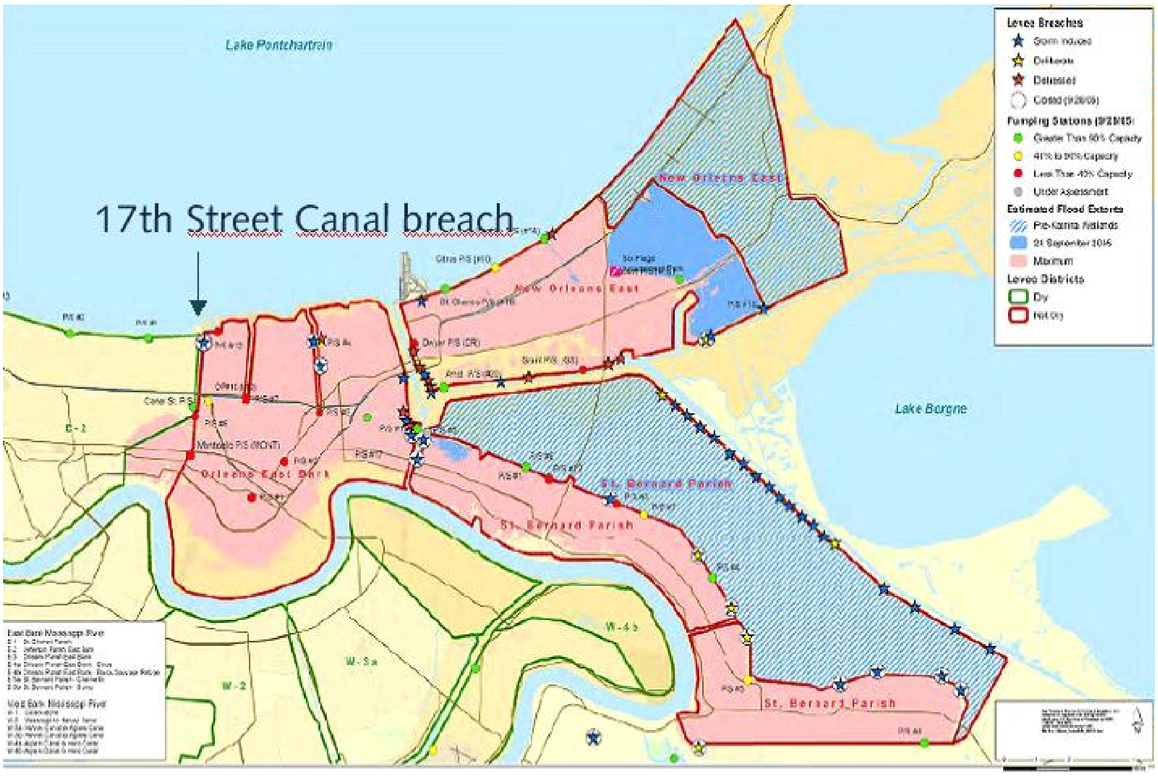


Figure 104 Map showing principal features of the main flood protection rings or 'polders' in the New Orleans area and the various breaches that occurred during Hurricane Katrina (indicated by the blue stars). [Modified after USACE, 2005)

Policy

With regard to flood protection and coastal management local governments in the US are responsible for land use and zoning decisions that direct floodplain and coastal development. However, numerous federal and state flood policies and programs influence local, and individual decision-making. The federal government funds flood control structures and projects, manages a flood insurance program, provides disaster assistance and it generates essential data through mapping and other efforts.

The federal role in flood control began in the late 19th century. Prompted by devastating floods in the Mississippi River basin, Congress created a commission to oversee the development of a levee system to control the river's flow. The Mississippi River Flood of 1927 and floods in the mid-1930s led to federal flood control investment. The Flood Control Act of 1936 declared flood control to be a 'proper' federal activity in the national interest. State and local governments are responsible for sharing (sponsoring) the construction cost of federally-funded flood control infrastructure and for its operation and maintenance. State and local entities may construct flood control infrastructure independently from the federal government, and are responsible for land use and zoning decisions guiding development in floodplains and coastal areas.

By the 1950s, it had become clear to Congress that the federal response to flood risk through structural flood controls and post-disaster assistance for flood victims was not good enough.

Pre-disaster funding via insurance began to look like an attractive alternative to flood control structures or disaster assistance. The National Flood Insurance Act of 1968 enabled the creation of the National Flood Insurance Program (NFIP). Coverage is available to all owners and occupants of insurable property in a participating community. Managing flood risk through insurance was expected to greatly reduce the reliance on federal disaster relief assistance because participating communities were expected to adopt and enforce building and other standards that could greatly reduce losses from a 100-year flood. However, the residual flood risk behind levees or downstream of dams remains largely unaccounted for in the NFIP and often is not incorporated into individual, local, and state decision-making.

A fundamental question being raised in the aftermath of Hurricanes Katrina and Rita is: do current federal policy, programs, practices result in an acceptable level of aggregate risk for the nation? And if not, how to reach acceptable levels. A similar development has taken place in many other countries. A good example is the United Kingdom (better: England and Wales). The flood protection policy form the late 20th century was very much based on local cost-benefit analysis. The national government only participated in protection scheme if the benefit-cost ratio was larger than 2. However, after a large series of riverine floods creating large damages and disruption, a more national policy has been developed. Not to the same extent as in the Netherlands with the legally prescribed safety standards following the catastrophic flood of 1953. In both countries however, the debate on how to deal with low probability- high risk events is ongoing.

At the regional level of the State of Louisiana coastal management has increasingly become an issue over the last decades of the 20th century. Wetland loss in coastal Louisiana has reached catastrophic proportions, with current losses of 25-35 square miles per year. The disappearance of Louisiana’s wetlands threatens the enormous productivity of its coastal ecosystems, the economic viability of its industries, and the safety of its residents. Coastal Louisiana is important to the local and national economies through oil and gas production, the number one port complex in the Nation, and international seafood and recreation industries. The infrastructure that supports these activities is interwoven with the unique ecosystem created by the Mississippi River in South Louisiana. Additionally, major flood control and river control civil works structures located in coastal Louisiana play an important role in providing for its habitation.

Increasing environmental awareness has led many to recognize the relationships of local and national development to losses being incurred by Louisiana's coastal wetlands and barrier shorelines. In 1998, the State of Louisiana and its Federal partners approved a coastal restoration plan entitled *Coast 2050: Toward a Sustainable Coastal Louisiana*. That document presented strategies jointly developed by Federal, State, and Local interests to address Louisiana's massive coastal land loss problem. For the first time, solutions were proposed to address fundamental ecosystem needs in order to prevent the loss of this natural treasure. By implementing the plan’s regional ecosystem strategies, it is envisioned that a sustainable ecosystem will be restored in coastal Louisiana, in large part by utilizing the same natural forces that initially built the landscape.

While the ultimate goal for coastal restoration under the Coast 2050 plan is to implement strategies throughout coastal Louisiana, the Barataria Basin is in dire need of immediate attention. On February 18, 2000, the USACE and Department of Natural Resources of the State of Louisiana (LADNR) signed a historic agreement to initiate large-scale action to

restore this basin. The Barataria Basin has tremendous potential for restoration because of nearby sediment resources in coastal bays, the Mississippi River, and in Federal and State waters of the Gulf of Mexico. USACE and State initiated the Louisiana Coastal Area study. This study will develop plans to submit to the United States Congress requesting authorization and construction funding for ecosystem restoration in the Barataria Basin under the Water Resources Development Act.

Administration and finance

The USACE (the civil works section to be more precise) is responsible for delivering the national policy on navigation, flood control and coastal restoration. The involvement of USACE flood control construction is predicated on the project being in the *national interest*, which is determined by the likelihood of widespread and general benefits, a shortfall in the local ability to solve the water resources problem, the national savings achieved, and precedent and law. Over the last century, many of the communities most prone to riverine flooding have been protected by significant investments in flood control infrastructure. Many of the current questions and concerns revolve around the following topics:

- whether the level of protection is sufficient if all consequences are considered (e.g., intensity and spread of urbanization, concentration of oil processing and distribution infrastructure);
- whether flood threat and vulnerability have changed (e.g., as the result of increases in ocean temperature, coastal wetlands losses; and the reliability of aging levees and dams); and
- how sufficient is the hurricane and storm protection for the nation’s coastal communities.

The USACE within the (financial) framework provided by Congress. The evaluation and recommendation of a flood control project by USACE involves multiple steps. After an initial reconnaissance study that is funded by the federal government, current policy is for the cost of the follow-on feasibility study to be split 50% federal - 50% non-federal; flood control and storm protection construction generally is split 65% federal - 35% non-federal. When Congress authorizes USACE to construct a project, the authorization generally is based on a report by the Chief of Engineers. In that report, it is typically recommended to build one of the alternative plans studied in the agency’s feasibility report, consisting of an evaluation of alternative plans, benefit-cost analysis, engineering analyses, and environmental impact assessments. The benefit-cost analysis of a project may result in a recommended plan for flood control infrastructure providing for protection greater than or less than the 100-year flood. Local project sponsors can request that a ‘locally preferred alternative’ be built, instead of the plan identified by the benefit-cost analysis. The NFIP creates incentives for communities to support flood control alternatives providing at least the 100-year level of protection, but the program provides few incentives for more protection.

For some local leaders and communities, the financial capital required to cost-share an USACE flood control project may represent a barrier to pursuing greater protection. The benefit-cost analysis focus and the national economic development benefits and does not constitute a comprehensive risk analysis, because the consequences considered are largely

limited to property damage, leaving out other potential consequences, such as loss of life, public health problems, and economic and social disruption. The Water Resources Development Act of 1986 (up for Congress now) requires USACE to address the prevention of loss of life in the formulation and evaluation of flood control projects. The Act will also authorize a number of coastal restoration and hurricane protection projects (such as the Barataria Bay).

As an indication: the overall budget for the USACE (Civil Works) for the fiscal year 2008 is approximately 5 billion US$ of which nearly 50% is to be spent on operation and maintenance.

The State of Louisiana has a number of authorities responsible for delivering the flood protection and coastal restoration policy:

- Department of Natural Resources (DNR);
- Department of Transport and Development (DoTD);
- Coastal Protection and Restoration Authority of Louisiana (CPRA).

Generally, the state finance their activities by taxation and general funds from the federal government. However, the policy goals formulated on flood protection and coastal restoration require funds far beyond this level. Coordination of state and federal funds is therefore necessary.

On a local level the levee boards and the municipalities play their significant role.

The levee boards are recently consolidated. This process had led to two levee boards, one on each side on the river: West bank and East bank. These levee boards are responsible for management and maintenance of the levees. The levee boards have more or less two ‘chains of command’. The general supervision of the levee boards is done by the State of Louisiana. On the technical side of the matter, the USACE conducts a yearly inspection of the state of the levees together with officials from the levee board. If necessary, this inspection may lead to an incident report of the USACE to the water boards. The ultimate consequences of such an incident report may be that the USACE does the required reinforcement works at the costs of the levee boards. The levee boards finance their activities by local taxation.

The municipalities (parishes) are responsible for managing the sewage system and internal drainage. The internal drainage largely depends on a large number of pumping stations taking the water out of the ‘bowl of metropolitan New Orleans’. There is however one exception: the former levee board in St Bernard Parish was responsible for internal drainage and this responsibility has been transferred to the consolidated levee board (east).

Taskforce HOPE

Directly after the floods due to Katrina and Rita a number of emergency operations started involving a number of taskforces. Taskforce Unwatering completed the unwatering of the city on October 11, 2005.

Taskforce Hope is aimed at:

- repairing the damage flood protection and internal drainage works before June 1st 2006 (start of the hurricane season; costs 1,5 billion US$);
- raising all levees to the originally authorized level before September 1st 2007 (costs included in the 1,5 billion US$ mentioned above);
- completing the authorized hurricane protection system before September 1st 2007 (costs 500 million US$);
- realizing a 100 years safety level for the urban areas by 2010 (costs 6 billion US$). Any further increase of safety levels is studied in LACPR.

CPRA and LACPR

Prior to the Katrina and Rita floods the State of Louisiana and the USACE already had formulated strategic goals on coastal restoration. After the floods the state created the Coastal Protection and Restoration Authority of Louisiana (CPRA) and authorized it to prepare a comprehensive master plan for a sustainable coast. CPRA is charged to coordinate the efforts of local, state and federal agencies to achieve long-term and comprehensive coastal protection and restoration. The main challenge is to integrate flood control and wetland restoration. In February 2007 a draft master plan was completed. Four main objectives were formulated:
reduce risk to economic assets;
restore sustainability of the coastal ecosystem;
maintain a diverse array of habitats for fish and wildlife;
sustain Louisiana's unique heritage and culture.
The final master plan will be presented to Louisiana Legislature in April 2007.

Directly after the Katrina and Rita floods the USACE prepared a Cat. 5 report to come up with an indication of the measures required to protect the greater New Orleans area against a Cat. 5 type of hurricane. Following this study Congress authorized the USACE to prepare a plan on Louisiana Coastal Protection and Restoration (LACPR) in close co-operation with the State of Louisiana. Both the Louisiana legislature and the United States Congress provided legislative directives to investigate and integrate the use of manmade structural, natural environmental, and public policy related measures. The LACPR project will integrate flood control, coastal restoration, and hurricane protection objectives into a consistent and interoperable plan. Based on the federal directive, the purpose and scope of this project is as follows:
The **purpose** of the project is to identify a plan for increased protection against storm surge equivalent to a Category 5 hurricane within South Louisiana.
The **scope** is to address the full range of flood control, coastal restoration, and hurricane protection measures needed for comprehensive Category 5 protection in South Louisiana.

The planning for LACPR is to have a final report ready by the end of 2007. A preliminary report was finished in June 2006.

The main challenge for the future lies in the integration and coordination between federal and state efforts.

I.3 Management and maintenance for LACPR

I.3.1 Multiple lines of defense

One of the important goals of LACPR is to provide a robust coastal flood protection scheme, based on a combination of measures.

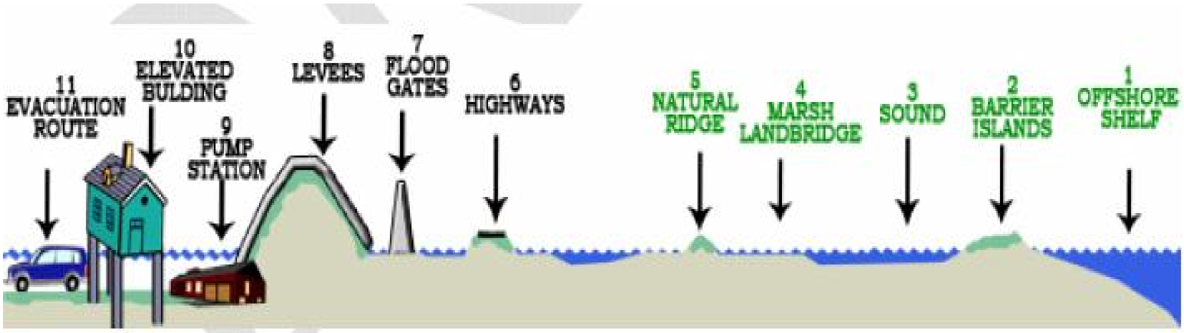


Figure 105 Multiple line of defense

The Dutch perspective on LACPR also features combination of measures. The main elements of these measures are:

- levees around metropolitan areas;
- marshland stabilization and development;
- levees and barriers to close of the estuaries;
- non-structural measures are included in all options.

The main component used to develop strategies are:

- Safe city: a series of interlinked levees directly around the metropolitan area of New Orleans. This system can be considered like a levee-ring area very much comparable to the Dutch situation. The Safe City measures also feature an option with a barrier in the Mississippi River.
- Pontchartrain and Barataria basin: for these two basins three main alternatives have been developed, being a levee/barrier-option, surge reduction measures and marshland stabilization and development. These alternatives can be used in combination.
- Birdfoot: creating tidal shortcut may enhance the natural processes of coastal sediment transport and salinity gradients. In addition to this, strategic dumping of sediment from the Mississippi delta can be used to supply the coastal areas.
- Non-structural measures.

Three strategies were developed using these components:

- Open estuary system: this roughly protects the metropolitan area of New Orleans with levees, stabilizes and develops the marshland, creates a shortcut in the Birdfoot and indicates non-structural measures to reduce the personal and economic risk;
- Semi-open system: this is equal to the open system with enhanced surge reduction measures (using passive measures);
- Closed system: this is equal to the semi-open system with structures (levees and barriers) to close off the estuaries.

Elements	Open	Semi-open	Closed
Safe city	Ring levee	Ring levee	Ring levee
Pontchartrain basin	Marshland stab/develop.	..+passive surge red.	..+levees/barriers
Barataria basin	Marshland stab/develop.	..+passive surge red.	..+levees/barriers
Birdfoot	Tidal shortcut	Tidal shortcut	Tidal shortcut
Non-structural measures	-	-	

The topic of management and maintenance will be described using the semi-open strategy as a starting point. The other strategies may require some additional remarks on management and maintenance.

I.3.2 Strategic and tactical goals

From the viewpoint of management and maintenance the strategic and tactical goals of the flood protection scheme need to be interlinked (also the operational goals need to be interlinked, but that topic will be dealt with later). The Dutch concept of safety assessment (every 5 years) including the risk assessment (every 25 to 50 years) can easily be transferred to the proposed strategies for the Louisiana coast and the New Orleans area.

The strategic goals are flood risk reduction and landscape stabilization in order to enable socio-economic developments. First of all, it must be realized that these goals can not be reached in a short period of time. It is fair to say that it will take decades (30-50 years) to reach realistic goals. This inevitably leads to the conclusion that during that period the strategic goals may already have to be adapted once or twice. This is a very important aspect in developing the management and maintenance strategy.

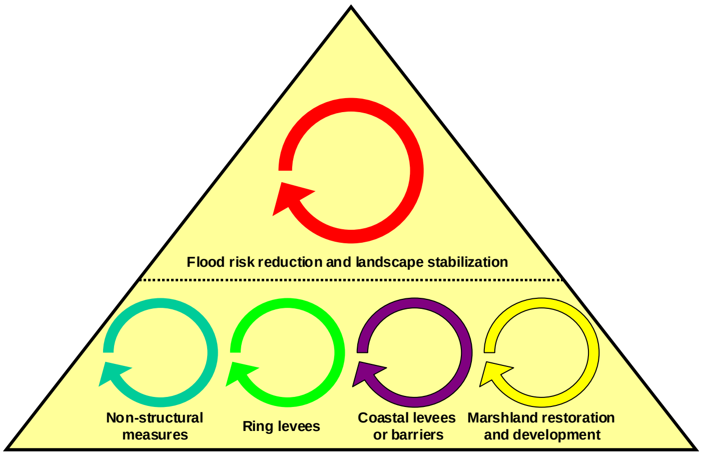


Figure 106 Strategic and tactical planning

The strategic goals are accomplished by the four types of proposed measures. Each of these measures have their own characteristics.

The non-structural measures can be implemented relatively quickly and are mostly logical no-regret measures. Due to its nature this type of measures however needs to be updated regularly. A yearly routine of practice, evaluation and adaptation is adequate.

The ring levees are meant to protect metropolitan areas from flooding. Depending on the required safety level (ranging from 10^{-5} to 10^{-2} per year) (re)construction of these embankments with a total length of several hundred kilometers will take approximately 5 years depending on the available budget. Also these measures can be described as no regret measures to be taken right away. The planning period for these levees should be somewhere between 50 and 200 years depending on the type of structures applied. Structures that are easily adapted can be designed using a short planning period, whereas the longer planning periods are required for (elements of the) structures that can not be adapted easily.

The coastal levees and/or barriers probably will take more time to design because the uncertainties in the performance and/or the complexity of the design. Probably it will take a number of years to come up with a design that fits in the strategic goals of the scheme. During this research and design period a number of large-scale pilot projects can be tested in practice.

Finally, the marshland restoration and development is a long term measure. It will take decades to ‘create’ significant developments. Also, the uncertainties attached to these measures are even greater than for the coastal levees and/or barriers. Large-scale tests in the field of these measures are definitely required.

The tactical goals for the various measures need to be projected on the strategic time span of, let’s say, 50 years. The combined effect of these measures changes over time (except for the non-structural measures).

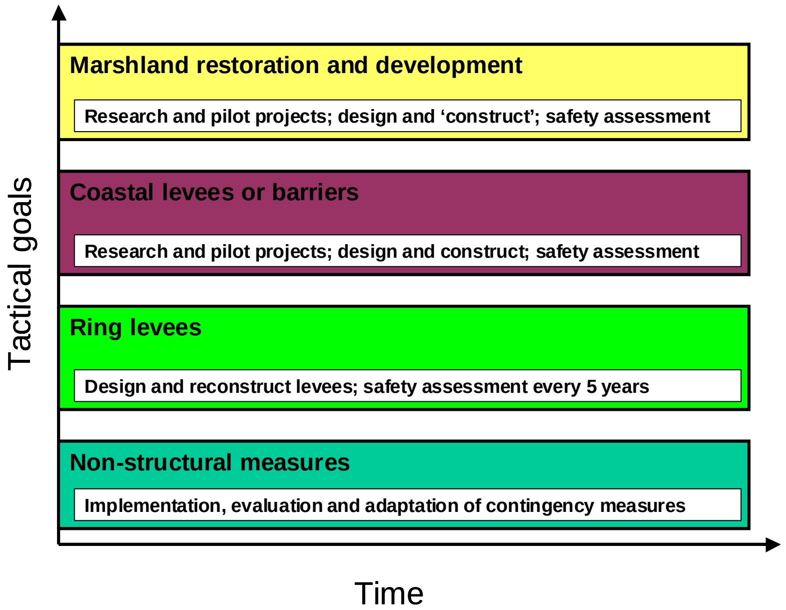


Figure 107 Tactical planning elements

After construction, the ring levees will slowly deteriorate due to the combined effect of sea level rise and settlements. That effect can be compensated once the measures ‘coastal levees’ or ‘marshland restoration and development’ start to be implemented. However, this requires assessing the actual performance of the various measures regularly. For the levees a 5 year period is considered to be adequate.

I.3.3 Operational goals

From the tactical goals the operational goals for management and maintenance can be derived.

To be added: info about water boards, CUR and STOWA.

I.3.4 Integration and coordination

The multiple line of defense approach is only as robust as the quality of managing and maintaining the separate lines. And in addition to this, the need for integrating and coordinating the activities of the various authorities involved is paramount.

The key discussion on management and maintenance is to find a fitting balance between the role and actions of the various authorities involved. Obviously, this study is not aimed at changing the way the US authorities are organized. But, based on the Dutch, European and American experiences a number of relevant criteria for the optimal management and maintenance situation can be derived.

1. adequate planning level;
2. local authority;
3. spatial and functional integration; and
4. clear responsibilities.

The first two criteria seem to be contradictory. First of all, it is necessary to have a planning level matching the scale of the natural system and the processes taking place. For example, the Mississippi River and the coast of the Gulf of Mexico need to be treated as a whole. On the other hand, flood protection measures need to be taken at the lowest level possible in order to keep local authorities involved and committed to their tasks. The local authorities are able to commit local residents and to find optimal solutions based on costs and benefits of flood protection measures.

The third criterion is based the ability to integrate the various functional demands in a spatial framework.

The fourth criterion is a clear separation of responsibilities including the need for checks and balances.

A number of sub-criteria can be developed from these four criteria:

1. adequate planning level:
   a) planning based on the natural systems involved, i.e. the river and the coastal system;
   b) planning based on functions assigned to these systems such as flood protection, navigation, …;
2. local authority:
   a) legislation, which gives (local) water authorities the authority to carry out their duties, to raise money and to enforce their rights;
   b) taxation of the people in the jurisdiction area of the water authority for generating income to carry out its duties;

   c) representation of stakeholders in the water authorities, to create stakeholder commitment and to ensure democratic decision-making;
   d) funding of large capital for major investments, which is mainly found within the private sector;
   e) institutional development, addressing trained staff and tools such as accurate cadastral and financial administrations, needed to allow for effective and efficient operation;
3. spatial and functional integration:
   a) functional integration;
   b) spatial integration;
4. clear responsibilities, including checks and balances.

I.3.5 Recommended situation

Based on the criteria the recommended situation for management and maintenance of the future flood protection scheme in the greater New Orleans area can be described as follows:

- political commitment to strategic management goals and the framework for tactical management goals and measures;
- designing and implementing the specific tactical measures within the approved framework;
- regular update of tactical planning (once every 1-5 years, depending on the type of measures);
- funding for operational management and maintenance.

Given the responsibilities of various authorities involved it seems to be required to discern two interlinked ‘chains of command’, leading to both federal and state government.

Item	Authority	Responsibilities
Integration/coordination	State	Risk management
Safe city	Levee board	M&M ring levee
Coastal management	USACE/State	M&M coastline
Coastal levees/barriers	USACE	M&M levees/barriers
Birdfoot/river management	USACE	River management
Non-structural measures	Municipality/State	Spatial planning

This section has to be completed / discuss with USACE whether such a table is useful. Add indication which changes in legislation, policy or practice are required.

I.3.6 Management and maintenance cycle

If the recommended situation would become reality, how would the management and maintenance cycle would like? This is illustrated in a (probably) fictitious management and maintenance cycle based on the assumptions

This section will be elaborated upon

I.3.7 Costs

Possibly indicate here costs for M&M based on Dutch cost parameters.

References

1. Technical Advisory committee on Water defense (1998), Fundamentals on water defense, The Netherlands
2. Jorissen, R.E. (1998), Safety, Risk and Flood Protection. In: R. Casale, G.B. Pedroli and P. Samuels (eds.), Ribamod, River basin modelling, management and flood mitigation, Concerted Action, Proceedings of the first workshop, pp. 57–72.
3. Vrijling J.K., Kuiper H., Jorissen R.E. and Klatter H.E. (1992), Ministry of Transport Public Works and Water Management, The maintenance of hydraulic structures. International Conference on Coastal Engineering ICCE'92, Venice, Italy.
4. Jorissen R.E., de Leeuw van Weenen R.P. (1994), Ministry of Transport Public Works and Water Management, Maintenance of hydraulic structures: example storm surge barrier Eastern Scheldt. International Commission on Large Dams ICOLD Congress '94, Durban, South Africa.
5. Jorissen R.E. et al (2000), Flooding risk in coastal areas - Risks, safety levels and probabilistic techniques in five countries along the North Sea coast, Ministry of Transport, Public Works and Water Management, The Hague, 61pp
6. Coastal Protection and Restoration Authority of Louisiana (2007), Integrated Ecosystem Restoration and Hurricane Protection, Draft Master Plan for a Sustainable Coast, Baton Rouge, Lousiana, US.
7. USACE (2006), Lousiana Coastal Protection and Restoration, Preliminary Technical Report, Washington/Vicksburg/New Orleans, US.
8. COMRISK (*reference to be added*)

J Lessons learned in Dutch water management

This appendix will be condensed, and repetition of items discussed in the previous appendix on management and maintenance will be deleted.

This appendix provides an overview of drawbacks and lessons learned in Dutch water management with focus on the Rhine-Meuse-Scheldt estuarine delta area

The Layer model, a conceptual approach to integrated assessment of land use and spatial planning

The Layer Model, introduced in the National Spatial Planning Strategy (2005) of the Netherlands, is proposed as a model for the analysis, integrated design and (participative) planning of land use and civil engineering works as well as for communicating about these matters. This approach allows plans that consider all three layers and the constraints they put on land use to be future-oriented, sustainable and usable.

The Layer Model distinguishes 3 physical layers. Each layer influences the spatial considerations and choices with respect to the other layers. Each layer is liable to changes, but the pace of changes differs. The slower the pace of change the more carefully you should be with implementing changes, because these changes will influence the future for a long time.

- Ground layer. Soil, (ground)water and flora and fauna in those environments. Changes take place in time spans of centuries (50 to 500 years) and are large scale and steadily going on. Wrong decisions will lead to unsustainability and large management efforts and costs in the future.
- Networks. All forms of visible and invisible infrastructure: waterways, civil-engineering works as levees, sluices, locks, etc., roads, railroads, pipe-lines. Changes take place in time spans of 25 up to 100 years.
- Occupation. Spatial patterns due to human use. Spaces for living, working and recreational activities. Changes take place relatively fast in periods of 10 to 25 years.

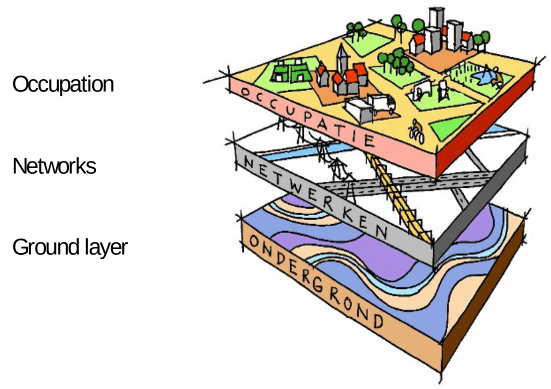


Figure 108 Layer Model

Besides these physical layers the cultural dimension is of importance. Governing the different paces of change and the social objectives within the 3 layers are a great challenge in spatial planning.

The *essence* of the Layer Model lies in the difference in dynamics between the layers. These dynamics determine the order of designing and planning land use.

First arrange the low dynamic ground layer. Then make use of or adapt to this ground layer in the higher dynamic network and occupation layers. The difference in dynamics should not be used rigidly hierarchic but should give good understanding of the choices to be made.

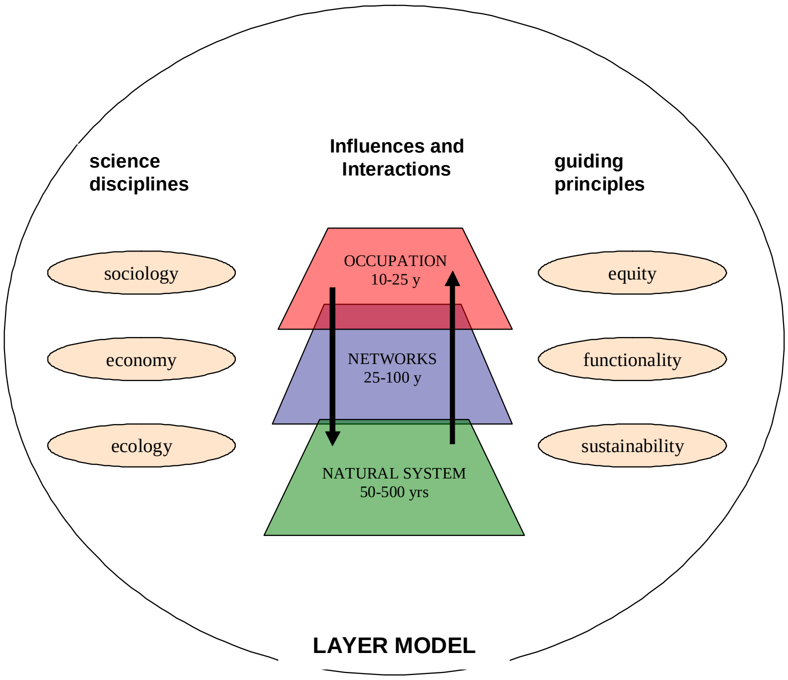
In analyzing and designing much consideration should be given to the properties and functions of the ground layer and the network layer, as well as the structural significance of both layers. Because these layers determine for the greater part the sustainability of land use and related management efforts and costs now and in the future.

In the planning stage, the processes in the different layers need to be considered in relation to each other. This will prevent conflicts now and in the future between different land use functions and will also create greater coherence in the measures to be taken. After all, intervention may (or better should) serve more than one policy objective at the same time.

Responsibilities for the surface layer and networks layer belong to governmental bodies. These make the framework for the interests of the occupation layer.

The *advantages* of applying the Layer Model:

- the model raises awareness about the complexity and forces to a broader integrated perception of matters;
- the model provides insight in integrated solutions;
- the model provides an overview of interests at stake, as well as the actors and stakeholders;
- the model allows a distinction between levels of scale within a problem: national, regional and local; and
- the model provides insight in choices made.



Link National Spatial Strategy document:
http://international.vrom.nl/docs/internationaal/engelsesamenvattingnr.pdf.

Influencing the ground layer

Looking through the spectacles of the Layer model the most important drawbacks and lessons learned from Dutch river and deltaic area water management all have to do with influencing the basic natural processes in the ground layer. This can not be a surprise, because civil-engineering measures influencing the ground layer have wide spread and long lasting effects as they influence the natural processes that shape the landscape. The abiotic natural processes are: tides, streams of water and groundwater, transport of (sometimes polluted) sediment and sedimentation and erosion, transport and sinks of nutrients. Biotic natural processes follow and have there landscape shaping effects, e.g.: growing of plants in intertidal areas speeding up sedimentation, erosion of areas due to changing in tides or change from tidal waters into stagnant lakes, hypoxia due to sinks of organic material in stratified water layers killing all higher life forms or toxic blue-green algae blooms due to an overdose of nutrients in created fresh water lakes.

The big picture

The Netherlands were formed by sediments deposited by the rivers Rhine, Meuse, Scheldt and Ems in their path to sea. The shaping of inhabitable land was speeded up by nature through sedimentation in the fresh-, brackish and saltmarshes in the estuaries coming into being in the gradient from river to sea. The inhabitants of these fertile areas soon took measures to prevent regular flooding. Levees were built and wetlands were reclaimed and drained for agricultural use. At that time it was not recognized that the building-up process of the land was effectively stopped by building levees. In addition, draining the (peat) land caused subsidence of the reclaimed land. With the harnessing of rivers with levees the sedimentation only takes place within the harnessed riverbed. Leaving less and less space

for high water flows. In addition, river regulation projects also disturbed the natural transport of sediments.

The Dutch economy thrived, and the Dutch became well-experienced in civil-engineering doing so the last 1000 years. But climate change with expected faster sea level rise and more extreme river flows now force the Dutch to prepare for keeping the country climate proof during the next centuries.

Executing the Delta Project after the 1953 flood harnessed and compartmentalized the combined estuaries of Rhine, Meuse and Scheldt far more then had been done before to bring the necessary safety against flooding. The Delta project also realized an inland tide-free navigation link between Rotterdam and Antwerp and opened up the area for recreational activities. However, the Dutch have learned that there are also drawbacks to the Delta Project.

Drawbacks Delta Project

Before executing the Delta Project the Delta area consisted of several estuaries, a transition area of the rivers Rhine, Meuse and Scheldt to the North Sea with gradual transitions from fresh to salt water and with tidal influences. An area dominated by dynamic equilibria between sedimentation and erosion. Through land reclamation areas behind levees were withdrawn from these dynamic equilibria.
Subsidence of reclaimed land by settling and draining of ground layers of peat and clay and lacking of further natural sedimentation led to frequent flooding during the last centuries. The last flood of 1953 with 1836 deaths and tremendous economic damage was the starting point of planning and executing the Delta project to secure the safety against flooding of the area.

During the execution of the Delta project (1958 – 1997) plans were changed through increasing environmental awareness. Instead of closing off the sea inlet of the Eastern Scheldt a storm surge barrier was built, finished in 1986. A second storm surge barrier was built in the main shipping way The New Waterway to the port of Rotterdam, finished in 1997.

The Delta project has - in spite of the ecologically induced adjustments of the original plans - changed the former multiple estuary into strictly separated water systems. Not only the land has been fixated by levees but also the water. During the years it has become more and more apparent that the loss of the dynamic estuarine conditions (tides mixing with incoming river flows carrying sediments, organic matter and nutrients) has ecological disadvantages with socio-economic effects for the use of the waters.

The main drawbacks in short:

- The artificial fresh lake Volkerak-Zoom copes with blue-green algae blooms due to incoming nutrient-rich river water. Studies are being carried out to restore estuarine conditions. Results are pointing in the direction to make it a salt water lake with as much water circulation and tidal fluctuations as possible.

- The artificial brackish Lake Veere coped with blooms of sea lettuce, green algae and lack of oxygen in the deeper parts due to inflow of nutrient rich water from agricultural land surrounding the lake. In 2004, a culvert to the tidal Eastern Scheldt became operational to flush the lake with salt water. Since then water quality has improved considerably. Studies are carried out to adjust management of unnatural water level (high in summer and low in wintertime to improve the drainage of surrounding agricultural land) to further improve the ecology of the lake.
- The artificial salt Lake Grevelingen copes with lack of oxygen in the deeper parts and changes in bottom fauna due to lack of water circulation. The situation has improved by building a culvert to the North Sea, but the lake is still slowly deteriorating. Studies will be undertaken to improve water quality and ecology by enlargement of the culvert with the North Sea and using a culvert with the Eastern Scheldt. Combination with a tidal energy plants will be studied as well.
- Building the Haringvliet sluices closing off this tidal inlet and controlling the riverflow of Rhine and Meuse to sea caused sedimentation of polluted material in the Biesbosch and Haringvliet and Hollands Diep. Migrating fish are now blocked by the sluices which also create an abrupt change from fresh to salt water. By 2008, the Haringvliet sluices will be opened a little bit to restore fish migration, enabling fishes to swim up and down the rivers Rhine and Meuse. To avoid negative side-effects for fresh water supply due to salt water intrusion, various modifications are necessary.
- A still unsolved side-effect of the storm surge barrier in the Eastern Scheldt is the steadily proceeding erosion of the tidal flats and salt marshes. This is caused by the disturbed dynamic hydro-morphological equilibrium due to the oversized tidal channels and reduced water exchange through the barrier. It remains unsure whether or not this development will be lead to an unacceptable situation. The problem is that it affects the protected habitat of tens of thousands of birds.
- Shoreline erosion problems had to be solved in the stagnant lakes. Measures to protect the shorelines and adjoining shallow waters of the created lakes from erosion by continuous attack of wind driven waves were carried out in the seventies and eighties.

The necessity of finding solutions for these problems is strengthened (and required) by the European Water Directive and the Birds and Habitat Directive. Both the ecological and water quality must be improved. The guiding principle behind the approach is responsibly repairing and strengthening the estuarine dynamics. The cohesion between the various bodies of water is essential here. Important issues to be solved remain:

- Next to coping with these drawbacks, the effects of climate change will have to anticipated and coped with: sea level rise, heavier storms, more intense rainfall, dryer summers, further salinization of (ground)water and seepage.
- What will be the functioning of the Delta waters in extreme conditions when temporarily excess river flow is stored in these waters when during a storm at sea the barriers are closed? A study for this function of Lake Volkerak-Zoom will be carried out the next years.
- Will a sea defense line of one high levee be sufficient in future? What are the possibilities and advantages and disadvantages of broader coastal zones with for example two levee lines and making use of natural sedimentation processes when still available?

New socio-economic issues

The capacity of the various shipping locks in the dams of the Delta works will impose restrictions on shipping to and from the Delta area harbors in the future. The capacity will have to be enlarged in future. Recreational sailing is also subject to the barrier effects of dams and locks. This puts a brake on economic growth of that sector.

The area also has many various other problems. The user pressure on the region from the surrounding urban areas is increasing. At the same time the number of inhabitants has recently dropped. The problems of agriculture – historically an important economic bearer – require modernization and renewal. Sustainable agriculture, in equilibrium with its environment, will continue to be necessary. Despite qualities such as water, nature and space, recreation is declining. Here too renewal and innovation are needed.

The lessons learned in short are:

- It is wise to bring flood defense measures in harmony with natural processes and the goods and services these processes provide us.
- Compartmentalizing of the Delta estuary leads to separation of water systems and reduction of natural water exchange. This diminishes resilience and flexibility for integrated water management and flood control. It may cause problems of erosion, sedimentation and water quality. And it may block water discharges needed in emergencies.
- Following this concept the best solution for the Dutch Delta estuary would be a more open system with large barriers and culverts not disturbing daily natural dynamics.
- Triggered by various incidents of intensive rainfalls in recent years and near river flooding in 1995, the need to continue raising public awareness about living with water in this low lying area became apparent. The Dutch have to live facing the water and not turning their backs to it. Facing it as both an enemy and as an ally. Before the water may surprise the Dutch as an enemy again, it is important to anticipate and innovate in a timely fashion.

Professor Henk Saeijs, one of the former directors of Rijkswaterstaat Zeeland summarized it in this way: ‘Mother Nature is the best engineer, think twice before you interfere’. When you act against nature you keep encountering unwanted effects.

K Project team

The following individuals, listed in the order of the appendices they contributed to, have participated in this study:

Person	Organization	Role / Expertise
Dr. Ad van der Spek	TNO	Geology
Mindert de Vries, MSc.	Delft Hydraulics	Ecology
Dirk-Jan Walstra, MSc.	Delft Hydraulics	Hydraulics, morphology
Maarten van Ormondt, MSc.	Delft Hydraulics	Hydraulics, morphology
Dr. Matthijs Kok	HKV	Risk-based approach
Dr. Bas Jonkman	Rijkswaterstaat	Risk-based approach
Dr. Meindert Van	Geodelft	Soft soil engineering
Jan Heemstra, MSc	Geodelft	Soft soil engineering
Dr. Jentsje van der Meer	Infram	Hydraulics / Levee design
Dr. Martin van der Meer	Fugro	Levee design
Dick Kevelam, MSc.	DHV	General planning, measures, structures
Gé Beaufort, MSc.	Rijkswaterstaat	Structures
Wim Kortlever, MSc.	Rijkswaterstaat	Structures
Erik Bijlsma, MSc.	Rijkswaterstaat	Structures
Dr. Bart Peerbolte	Haskoning	Coastal engineering
Ms. Marije Schuurman	DHV	Graphics
Ferry Vis, MSc	Alkyon	Navigation / port development
Leo Adriaanse, MSc.	Rijkswaterstaat	Spatial planning
Richard Jorissen, MSc.	Rijkswaterstaat	Management and Maintenance
Ms. Liesbeth Eshuis, MSc.	Arcadis	Planning framework
Piet Dircke, MSc.	Arcadis	General planning
Ms. Willemijn Oosterwijk	Arcadis	Project Management Assistant
Ms. Marja Menke, MSc.	Arcadis	Deputy project leader; planning framework
Jos Dijkman, MSc.	Delft Hydraulics	Project leader

Team members from Rijkswaterstaat, a governmental organization under the Netherlands Ministry of Transport, Public Works and Water Management, have participated in this research project on a personal title. Their contributions to this report do not necessarily represent the official views of the Ministry.